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Mobility Patterns in Time and Space

Planning and Managing for Sustainable Tourism

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Dissertation submitted in partial fulfilment of a
Philosophiae Doctor degree in Tourism Studies

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Abstract

This study evaluates a novel methodological approach for analyzing tourism mobility patterns in time and space within regions characterized by core-periphery mobility patterns, with Iceland and its key nature-based destinations serving as the study area. Traditional analyses often rely on overnight stay data; however, this approach fails to capture the full scope of visitor behavior in core-periphery contexts, where tourists frequently base themselves in urban cores and undertake day trips to rural peripheries. This study aims to enhance understanding of tourism mobility patterns in Iceland in relation to the aims of the Icelandic tourism authorities to improve sustainable tourism planning and management.

The study emphasizes methodological advancements and the integration of diverse datasets to enhance analytical accuracy. Vehicle counters at nature-based destinations were employed to track visitor movements, enabling comparison with overnight stay data and departure data from Keflavík International Airport. Converting vehicle counts into visitor estimates formed the basis of the methodological exploration detailed in Papers 1 and 2. Paper 3 utilized these data to analyze mobility patterns across Iceland. Paper 4 tested Bluetooth sensors in the Jökulsárlón area, assessing their utility for tracking directional vehicle flows.

The findings highlight the efficacy and cost-efficiency of automated methods. These tools overcome limitations related to recall bias and provide robust baseline data on mobility patterns. While these methods offer valuable insights, understanding the underlying motivations behind mobility patterns necessitates supplementary approaches. This methodology represents a significant advancement in studying tourism mobility in core-periphery regions, such as the Arctic regions.

Útdráttur

Markmið rannsóknarinnar er að prófa og meta nýjar aðferðir til að greina ferðaleiðir ferðamanna á svæðum sem einkennast af sterkum kjarnasvæðum, oft borgum, sem stýra flæðinu út á jaðarsvæðin. Rannsóknarsvæðið er Ísland og vinsælir náttúrstaðir. Gistináttagögn hafa mikið verið notuð til að greina ferðaleiðir. Slík gögn segja einungis hálfa söguna á stöðum eins og Íslandi, þar sem ferðamenn dvelja mikið til í þéttbýli og fara þaðan í dagsferðir á nærliggjandi náttúrustaði. Gert er ráð fyrir að niðurstöður rannsóknarinnar geti aðstoðað stjórnvöld til að ná markmiðum sínum um að skipuleggja og stjórna ferðaþjónustunni á sjálfbæran hátt.

Rannsóknin leggur áherslu á að bæta aðferðafræði og nýtingu ólíkra gagnasetta til að fá skýrari mynd af stöðunni. Til að greina ferðaleiðirnar, var að mestu notast við bifreiðateljara á náttúrustöðum. Gögnin voru borin saman við gagnasett um gistinætur og fjölda ferðamanna um Keflavíkurflugvöll. Í greinum 1 og 2 var nýting bifreiðateljara til að áætla fjölda ferðamanna á náttúrustöðum lýst. Í grein 3 voru gögnin svo notuð til að greina ferðaleiðir um Ísland. Í grein 4 voru tveir Bluetooth skynjarar notaðir til að greina stefnu farartækja.

Niðurstöðurnar sýna fram á mikilvægi sjálfvirkra rannsóknaaðferða. Þær eru hagkvæmar í framkvæmd og ekki þarf að treysta á minni þátttakenda um hvert þeir fóru. Aðferðafræðin sem hér er kynnt veitir góð grunngögn um ferðamynstur og leiðir og er mikilvæg viðbót við aðrar aðferðir. Aðferðafræðin er mikilvæg framþróun í rannsóknum á ferðaleiðum á svæðum eins og Íslandi og heimskautasvæðunum, sem einkennast af sterkum kjarna þaðan sem flæðið er út á jaðarsvæðin.

To my children

Arna and Bjarki

Table of Contents

List of Figures ... **ix**

Acknowledgements ... **xi**

1 Introduction ... **1**
1.1 The Aim of the Research and Structure ... 2
1.2 Iceland ... 3

2 Theoretical Framework ... **7**
2.1 Mobility Patterns in Time and Space ... 7
2.2 Sustainable Tourism ... 8
2.3 Sustainable Tourism Planning and Management ... 9
2.4 Seasonality and Sustainable Tourism Management ... 11
2.5 Nature-Based Tourism in the Arctic ... 12
2.6 Mobility Measures ... 12

3 Methodology ... **15**
3.1 Methods ... 15
3.2 Study Sites ... 16
3.3 Research Approach ... 17

4 Summary of Papers ... **19**
4.1 Paper 1 ... 19
4.2 Paper 2 ... 20
4.3 Paper 3 ... 21
4.4 Paper 4 ... 22

5 Discussions and Conclusions ... **25**
5.1 The Value of the Research Method for Analysing Tourism Mobility Patterns ... 26
5.2 The Relationship Between Mobility Patterns in Iceland and the Aim of the Icelandic Tourism Authorities to Plan and Manage Sustainable Tourism ... 27
5.3 Visitor Numbers at Nature-based Destinations and Sustainable Tourism Planning and Management ... 28
5.4 Final Remarks and Future Research ... 29

References ... **33**

Paper 1 ... **55**

Paper 2 ... **65**

Paper 3 ... **77**

Paper 4 ... **101**

List of Figures

Figure 1. Research Structure 3

Figure 2. Visitors Departing Keflavík International Airport (The Icelandic Tourist Board, 2025). 4

Figure 3. The Study Sites 17

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1 Introduction

During the last two decades, interest has grown for the Arctic as a tourist destination (Maher et al., 2022; Rantala et al., 2019). While the precise borders of the Arctic cannot be exclusively defined, the Arctic Circle, which encompasses the region north of latitude 66°34', is used as a boundary marker for the region. Although other definitions are available, this research uses the Arctic Council (Arctic Monitoring and Assessment Programme - AMAP) definition of the Arctic as it includes aspects such as political borders, vegetation zones, permafrost boundaries, and key oceanographic characteristics (Icelandic Arctic Cooperation Network, n.y.). According to the Arctic Council's definition, areas of eight countries belong partly or wholly to the Arctic: northern and north-western Canada, Alaska (United States), northern Russia, Greenland, northern Norway, northern Sweden, northern Finland, and Iceland (Arctic Council, 2024).

The Arctic regions are often characterised by low population densities spread across vast areas (Rantala et al., 2019). Most of the residents in the Arctic live in urban centres, and the distance between these centres can be considerable. For example, based on data from 2024, 62% of Icelandic residents live in the capital area and the rest live in towns and villages distributed around the country (Statistics Iceland, 2025a). Another similarity among the Arctic regions is that they have relied on resource extraction industries, such as oil, gas, mining, forestry, and fishing. In Iceland, the economy has been largely based on the exploitation of natural resources, for example, fisheries, agriculture, and energy-intensive industries. In recent years, the diversity of the economy has significantly increased, along with rapid technological progress, an increased focus on innovation and creative industries, and the growth of the tourism industry.

The Arctic regions share many similarities in tourism, such as high regional seasonality and ecological vulnerability. Tourism seasonality affects various aspects, such as the annual stability of work; uses of various infrastructure, for example, accommodation for tourists and migrant workers; the transportation system; and the health care system (Rantala et al., 2019). Another tourism similarity in the Arctic is that a dominant gateway, usually an airport, is located within or close to the strong core of each region, often a city (Carson et al., 2020). Since the main attraction of the Arctic is nature and nature-based destinations, the cores dominate the Arctic mobility patterns that spread into the rural, natural areas (Maher et al., 2022; Müller, 2025). Furthermore, some of the natural areas may be a significant distance from the urban core.

Some parts of the Arctic, including Norway, Sweden, Finland, Iceland, and Alaska, have experienced a significant increase in foreign visitor numbers in recent years, and research suggests that Greenland, Canada, and the Russian Arctic will experience similar increases (Runge et al., 2020). After the Russian invasion of Ukraine, tourism in Russia has dropped. Several governments have cautioned against travelling to Russia, and the airline routes between Russia and western countries have been closed. This context will influence the future increase in tourism to Russia. In Greenland, infrastructure improvements are underway. A new international airport was opened in the capital of Nuuk in November 2024 and another airport capable to accommodate international flight is expected to open in Ilulissat in Northwest of Greenland in 2026 (Ren et al., 2024). It is expected that tourism in the Arctic will continue to increase in the coming future (Müller, 2025)

1.1 The Aim of the Research and Structure

The aim of this doctoral thesis is to develop and test a multi-layered research method to analyse tourism mobility patterns in time and space in regions where tourism is characterized by a strong urban core, from which the flow of tourists is concentrated into the rural periphery. The analysis focuses on nature-based destinations in Iceland, and the methodology was designed for this specific context. Nevertheless, the research method is expected to be useful for other regions, especially Arctic regions, that have similar mobility patterns as Iceland. The results of the study are expected to increase knowledge and understanding of tourism mobility patterns in time and space in Iceland in relation to the Icelandic tourism authorities' aims to improve sustainable tourism planning and management.

Even though this research focuses on developing methods to analyse tourism mobility patterns, the data provided from the research also contributes to tourism policy making and evaluation of past and currents efforts to plan and manage tourism in Iceland. For decades, researchers and practitioners have focused on reducing regional seasonality and influencing international tourists to visit less popular destinations to distribute regional revenues more evenly around Iceland. The aim of the study is not to scrutinize the tourism policies of Icelandic authorities, but rather to demonstrate how traffic measurements are a necessary and useful element in underpinning rational policy. To accomplish the aim of the research, the following research questions are addressed:

1. How are the research methods valuable for analysing tourism mobility in regions characterised by a strong core from which the flow of tourism moves toward peripheral, rural areas?

2. How do the mobility patterns in Iceland relate to the Icelandic tourism authorities' aims to better plan and manage sustainable tourism?

3. How does the analysis of visitor numbers at nature-based destinations contribute to the planning and management of sustainable tourism in similar regions, such as the Arctic regions?

This Ph.D. project consists of four research papers (Section 4) that are integrated into a common context in this synopsis. The synopsis presents the theoretical background of the Ph.D. project, the research settings, and the methods. Papers 1, 2, and 4 address Research Question 1. Papers 1 and 2 analyse the research methods involved when vehicle counters are used to compute the number of visitors from the number of vehicles. Paper 4 describes the research method of using Bluetooth sensors to analyse regional tourism mobility in time and space. Papers 3 and 4 address Research Questions 2 and 3 in relation to tourism mobility in time and space, and sustainable tourism planning and management. Figure 1 shows the structure of the research.

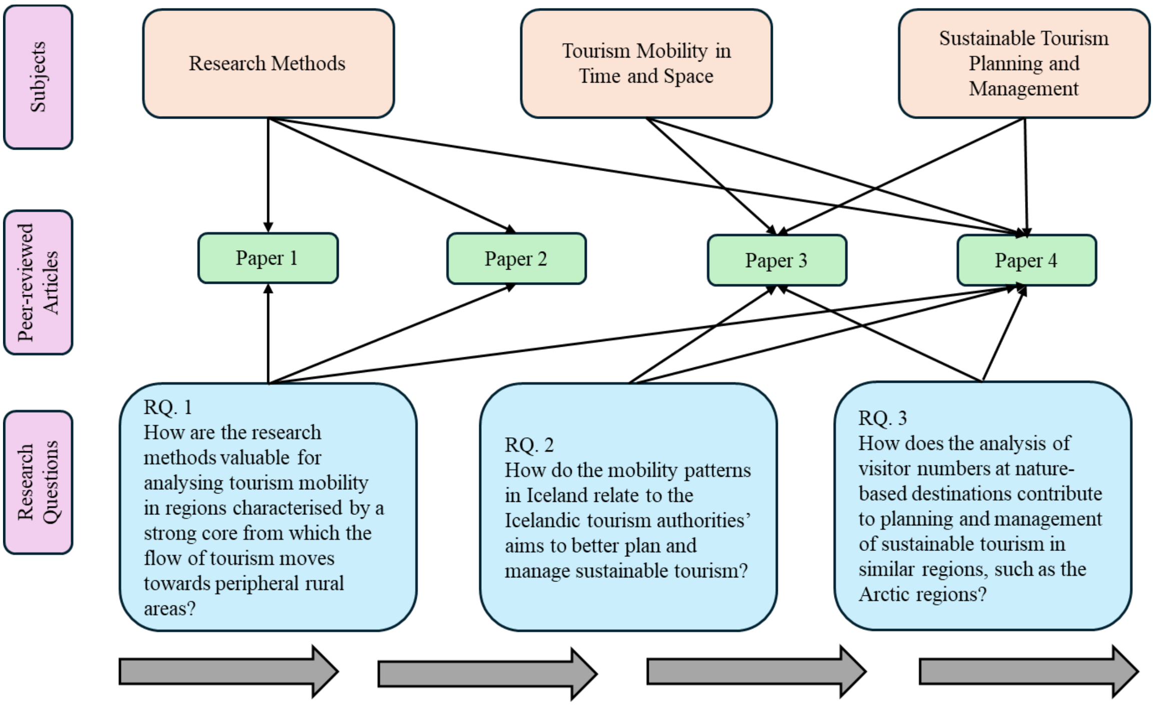

Figure 1. Research Structure

1.2 Iceland

Even though Iceland is far north in the Atlantic Ocean, during the last decade the country has enjoyed increased popularity among tourists. In 2010, 459,000 tourists visited Iceland, in 2015 the total was 1.3 million, and in 2018 the annual tourists totalled 2.3 million. Tourism decreased by 14% from 2018 to 2019, and during the COVID-19 pandemic, tourism collapsed as international travel was limited. Tourism has recovered after the pandemic, given that 2.2 million tourists visited in 2023 and almost 2.3 million visited in 2024 (The Icelandic Tourist Board, 2025). Several reasons have been linked to the increase in tourist numbers (Papers 3 & 4). For example, the 2008 international financial crisis hit Iceland considerably hard and made the expensive country more affordable for most tourists. Moreover, the eruption in Eyjafjallajökull in 2010 stranded many travellers worldwide because fine volcanic ash was dispersed into the air, and the event created significant international media attention (Benediktsson et al., 2011). Furthermore, increased interest in the Arctic as a tourist destination (Maher et al., 2022) has also benefitted Iceland as a sub-Arctic country located between North America and Europe with good air connectivity (IATA, n.d.; Jóhannesson et al., 2010).

Although the visitor numbers collapsed at the beginning of the COVID-19 pandemic in April 2020, the annual number of visitors in 2020 was 482,000, which is nearly equivalent to the 459,000 annual visitors in 2010. In June 2021, the visitor numbers started to recover. The second half of 2022 was similar to the second half of 2019, and the annual visitors in 2018, 2023, and 2024 were similar. Therefore, annual tourism has nearly returned to the pre-pandemic level (Figure 2).

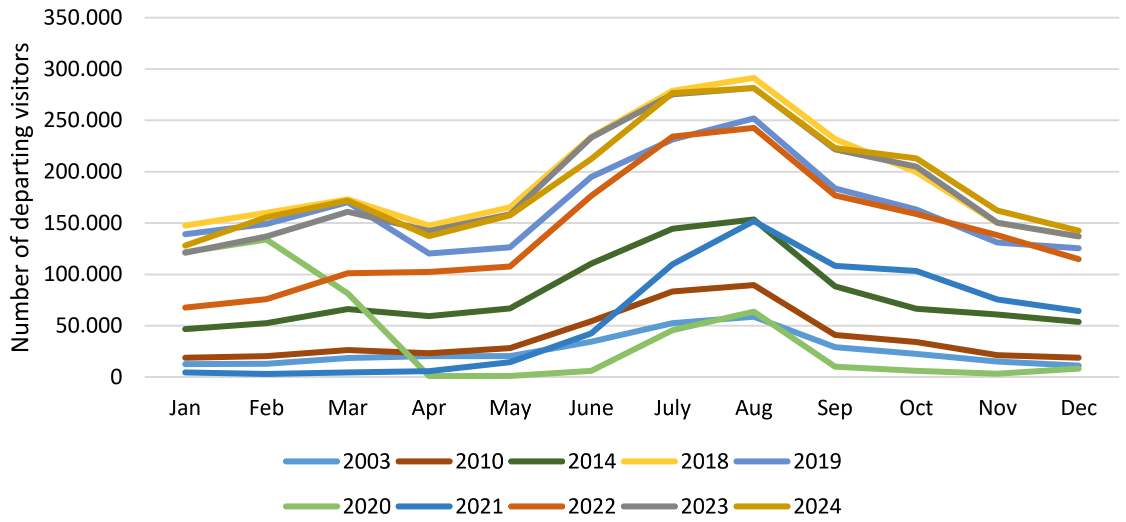

Figure 2. Visitors Departing Keflavík International Airport (The Icelandic Tourist Board, 2025).

The rapid growth in the tourism sector boosted the national economy and has made the tourism industry the most important industry in Icelandic economy in terms of foreign currency income (Statistics Iceland, 2025b). The increase also brought many challenges, such as environmental degradation and overcrowding at the most popular sites (Sæþórsdóttir et al., 2020a, 2020b). Iceland's sub-Arctic flora is particularly susceptible to environmental degradation from overcrowding and trampling, and a relatively small number of visitors can cause significant impact (Jóhannesson et al., 2010; Ólafsdóttir & Runnström, 2013; Sæþórsdóttir, 2014). Then, in certain areas of the country, the increase has also exacerbated pressure on the local housing market, the health care system, and the transportation system (Mixa & Loftsdóttir, 2024; Thórhallsdóttir & Ólafsson, 2017). The sector has also outgrown the domestic labour supply and is heavily and increasingly reliant on migrant workers (Júlíusdóttir & Halldórsdóttir, 2020; Skaptadóttir & Loftsdóttir, 2016).

To address the challenges from the great increase of tourist numbers, in 2015 Iceland's national tourism authorities established the Tourism Task Force to lay the groundwork for an effective tourism policy based on sustainable tourism management. This initiative was in operation from 2015 to 2020 (see Section 3). In 2024, a new tourism policy was accepted, and it emphasizes that tourism in Iceland should be both profitable and competitive while remaining in harmony with the country's natural environment and its people. The policy envisions Iceland will be a global leader in sustainable development and will be at the forefront of sustainable tourism by 2030 (Government of Iceland, 2024).

For decades, Icelandic tourism authorities have attempted to promote sustainable tourism planning and management (Jóhannesson et al., 2010). This focus has been loosely translated into two main aims: reduce regional seasonality and influence international visitors to travel to less popular destinations. The aims are set to protect nature, distribute revenues from tourism more evenly around the country, and protect both locals and tourists from the negative experiences of tourism (Paper 3). While seasonality in tourist numbers, which is measured with the Gini coefficient, has been decreasing overall for Iceland, regional seasonality is still relatively high outside of the southwest and south regions, (Thórhallsdóttir & Ólafsson, 2017; Thórhallsdóttir et al., 2024) (Papers 1 and 3). The dominant gateway to Iceland, Keflavík International Airport, is located in this area, and it is used by 99% of all international visitors (The Icelandic Tourist Board, 2025). The airport is less than an hour's drive from the capital city of Reykjavík and its surrounding municipalities. Reykjavík is the single most visited destination in Iceland and serves as an independent destination and basecamp (Huijbens & Jóhannesson, 2020; Jóhannesson & Welling, 2020), as well as a gateway to other destinations. From Reykjavík, visitors commonly drive in a rental car (Guðmundsson, 2020) to various nature-based destinations scattered around the country, but they mostly follow a route from the south to the southeast (Paper 3). The tourism authorities consider the regional seasonality to be the main challenge for the development of a sustainable tourism industry in Iceland (Government of Iceland, n.d.).

Concrete examples of government efforts working towards more sustainable tourism are the establishment of the Tourist Site Protection Fund, the National Plan on the Development of Tourist Sites (Lög um landsáætlun um uppbyggingu innviða til verndar náttúru og menningarsögulegum minjum nr. 20/2016), and the development of Vakinn in 2012, which is a quality and environmental assurance initiative (The Icelandic Tourist Board, n.d.-a). The Tourist Site Protection Fund was established to promote the development, maintenance, and protection of tourist attractions and tourist routes in Iceland and also to alleviate pressure on highly visited sites by increasing the number of alternative tourist sites (The Icelandic Tourist Board, n.d.-b). The National Plan aims to formulate and coordinate a strategy for the development, operation, and maintenance of infrastructure in the interest of nature conservation and the protection of cultural and historical monuments due to pressure caused by tourism and outdoor recreation (Lög um landsáætlun um uppbyggingu innviða til verndar náttúru og menningarsögulegum minjum nr. 20/2016).

2 Theoretical Framework

2.1 Mobility Patterns in Time and Space

Everyday life is full of constraints that shape peoples' mobility routines in time and space, such as commuting to and from work (Kang, 2016), and the same applies to peoples' travels, which are also constrained by time and space resources (Zillinger, 2007). Over the last few decades, tourism mobility has been changing. Before, the majority of tourists tended to travel to a single tourist site, for example, often to a Mediterranean beach, and then returned home again (Urry & Larsen, 2011). More recently, tourists have multiple opportunities and choices to travel between unplanned sites. However, even when tourists have more options, they are still constrained by time in their mobility patterns.

This thesis addresses Hägerstrand's (1970) concept of 'time geography'. Initially, this concept focused on daily routines, movements, and the interactions of individuals in time and space, such as commuting and local activities. Time is a limited resource that influences how far in space one can travel. According to the time geography concept, the mobility options available to individuals are shaped by three time-space constraints:

- *capability constraints*, which encompass the physical needs and abilities of a person;
- *coupling constraints*, which involve the necessity of interacting with other individuals or objects across time-space paths to engage in an activity;
- *authority constraints*, which pertain to the laws, norms, and social barriers present in an individual's environment. (Hägerstrand, 1970)

These constraints, and the location of a destination, the duration of activities, and the travel speed influence people's mobility patterns. In tourism studies, time geography is useful for examining how tourists' behaviour, choices, and experiences unfold across time and space, which helps researchers understand travel patterns, destination use, and even environmental impact (Shoval & Ahas, 2016). Researchers have used various datasets to analyse tourist activities and preferences over time and space, including questionnaires, interviews, GPS tracking (Shoval & Isaacson, 2007; Sveinsdóttir et al., 2025), and geo-tagged social media data from Twitter and Flickr (Bishop et al., 2024; Li et al., 2013). In this thesis, I use time geography to explain mobility patterns in time and space in relation to seasonality, length of stay in the country, distance from a starting point, and access to a site. The study did not collect data on individual mobility options nor on their motivations. Therefore, this research can only answer questions about the flow of visitors not why it is as it is.

This thesis also explores distance decay, which is a concept related to Hägerstrand's (1970) time geography and explains why visitation to a site decreases with increased distance

(Hooper, 2015). In other words, the farther away a destination is from a starting point, the fewer visitors it will attract (Yee & Ismail, 2020). Furthermore, if many destinations provide similar experiences, the one closest to the starting point is likely to be the most visited (Hooper, 2015). However, a site can overcome such distance effects if it is unique and accessible (McKercher & Lew, 2003).

In recent years transportation development has significantly decreased travel time, and in turn, it has expanded spatial mobility (Hall, 2005; Rosello et al., 2004). The use of rental cars has also increased, allowing tourists to travel faster, and farther, in less time than was previously possible (Dickinson et al., 2013). This opportunity gives them more flexibility and autonomy in planning their trips compared to using public transport or fixed-route tour busses. Therefore, rural destinations that are farther away from an urban core are generally becoming more accessible than they were previously (Beeco et al., 2013).

Understanding the mobility patterns of tourists, including their destinations in time and space, is essential for sustainable tourism management (Lew & McKercher, 2006). The mobility patterns of tourists relates to how services, such as transportation (Scuttari et al., 2013), accessibility to a destination (McKercher & Lew, 2003), distance (McKercher, 2018), and diverse infrastructure, are planned and managed (De Cantis et al., 2015).

2.2 Sustainable Tourism

International tourism grew rapidly during the second half of the 20th century because of economic and social changes in people's lives in the Western world. Developments in the work field and increased leisure time gave people the opportunity to travel abroad during their holidays (Urry & Larsen, 2011). During the last two decades, annual international tourist arrivals have increased exponentially. In 2000, they were 687 million and in 2019 they were 1.465 billion (World Tourism Organization (UNWTO), 2023). Although international tourism significantly decreased during the COVID-19 pandemic, in 2023 it amounted to almost 90% of the highest pre-pandemic levels, estimated at 1.3 billion international arrivals (UN Tourism, 2024).

The rapid growth of international tourism during the second half of the 20th century also drew attention to the potentially destructive environmental and socio-cultural effects of tourism (Saarinen, 2021). From the 1990s onwards, the term 'sustainable tourism development' has occupied a position in academic tourism studies, as well as among practitioners in tourism policy-making and planning (Sharpley, 2009). Over the past two decades, sustainability has emerged as a key concept in tourism policies globally (Saarinen, 2021) and has also become a focal point for regional development initiatives (Broegaard et al., 2022; Edvardsdóttir et al., 2023). Despite the growing focus on sustainability, the use of the sustainability concept has been criticised by scholars who argue it inadequately addresses practical needs and challenges (Bramwell, 2015; Sharpley, 2020). Moreover, after decades of use, a divide occurs between theory/policy and practice and scant evidence of sustainable tourism development in the sector (Sharpley, 2020).

The literature on sustainable tourism is extensive, and Cooper (2023) found at least 20 overarching definitions of the concept. Many of the definitions were to some extent variations of other older ones. According to Cooper (2023), the most popular aspects of the 20 definitions in the review are economic, environmental, and social factors. This synthesis aligns well with the widely employed model of sustainability.

Most of the sustainable tourism definitions derive from the World Tourism Organisation (UNTWO) policy documents (Mihalic et al., 2021; Sharpley, 2009). The UNWTO is dedicated to promoting responsible, sustainable, and universally accessible tourism (World Tourism Organization (UNWTO), 2016). Initially, the UNWTO's concept of sustainable tourism was influenced by the Brundtland Commission's report *Our Common Future,* published in 1987, which defines sustainable development as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (World Commission on Environment and Development, 1987). In the manner, sustainable tourism aims to meet the needs of current tourists and host regions while safeguarding opportunities for the future (Sharpley, 2020). Over time, the UNWTO and other organizations have expanded this definition (Petrevska et al., 2020). For instance, the United Nations Environment Program (UNEP) and the UNWTO have redefined sustainable tourism to consider the current and future economic, social, and environmental impacts; to address the needs of visitors, the industry, the environment, and the host communities. Notably, the objective to meet the 'needs of the industry' is emphasised compared to the original 1993 conceptualization (United Nations Environment Programme (UNEP), 2005). The previous three pillars of sustainability—economic, environmental, and socio-cultural—expanded to four, with the cultural pillar being considered separately from the social pillar.

Iceland's current tourism policy extends to 2030 and focuses on achieving balance and integration across these four key pillars (Global Sustainable Tourism Council, 2024). Since 2024, the Icelandic Tourist Board has been a member of the Global Sustainable Tourism Council (GTSC), which is approved by WTO and provides guidance on sustainability for destinations and countries.

Globally, policy-making has shifted from government to governance; in other words, more and diverse actors are involved in the process of policy-making, for example, local residents, private companies, NGOs, and public institutions (Hall, 2011). This practice is also the case in Iceland (Government of Iceland, 2024).

2.3 Sustainable Tourism Planning and Management

Multiple impacts from tourism can be considered as both positive and negative. Due to the positive economic impacts of the tourism industry, tourism is often considered to be a vehicle for regional development, especially in declining rural areas (Kauppila et al., 2009). However, this outcome is not guaranteed as tourism may also have negative impacts (Árnason & Kolbrúnardóttir, 2019) on nature, and many other social impacts may also occur, such as on the housing market and on health care, especially in rural areas (Butler, 1999).

Therefore, knowing the actual or likely mobility patterns of visitors in time and space is essential to plan and manage tourism sustainably in the future (Lew & McKercher, 2006).

Sustainable tourism management aims to minimise the negative impacts that can occur from tourism, for example, on nature, local communities, and the tourists themselves. Therefore, many countries have developed strategies based on the sustainability pillars (economic, social, cultural, and environmental), seeking to balance the impacts of tourism with regard to these aspects (Mihalic et al., 2021).

For sustainable management, tourism authorities often lack comprehensive data on tourists' daily activities and destinations. Therefore, little is known about mobility patterns between overnight stays. Data on overnight stays is frequently collected by governments (Runge et al., 2020), as well as data from bank card transactions, as in Spain (Sobolevsky et al., 2014), and from smart travel data, as in London, Paris, and Hong Kong (Gutiérrez et al., 2020). In recent years, data from smart devices, such as cell phones, have also been used to analyse tourism mobility (Hamstead et al., 2018). These data all have pros and cons when analysing tourism mobility. For example, the overnight stay data show where the visitors slept during the night, but not where they went during the day; therefore, such data does not provide key information for destinations, especially for rural nature sites in the Arctic that tourists travel to during the day from a strong core (Runge et al., 2020). These day-time destinations are generally the places most impacted by tourism. According to Runge et al. (2020), knowing how and where tourism booms are distributed at a local scale across landscapes is crucial to manage the impacts on the host communities and natural environments.

Data on spatial visitation, trends and tourism activities are rarely collected in the Arctic. This is a big challenge for tourism authorities when planning and managing for sustainable tourism (Runge et al., 2020). The Arctic regions have been gaining popularity as tourist destinations, notably Lapland in northern Finland, Northern Norway, and Iceland (Maher et al., 2022). These regions have many similarities, such as a low population density that is spread across a vast area. They also tend to have one strong core, where most of the population lives, and these cores are often centres of decision-making and services for the region (Stuart et al., 2005). In the Arctic, tourists tend to stay overnight in these centres and take day tours into the peripheral rural areas. Peripheral areas often lack infrastructure of various kinds, such as hotels and an efficient transportation system. Urban areas are also often perceived as offering better value for money, more choices, and higher standards compared to peripheral rural areas (Carson et al., 2020). This preference for urban areas is prevalent in various Arctic countries and other regions characterised by long distances between service hubs and natural attractions (Müller et al., 2020). An important consequence of an urban centre serving as a basecamp is that excursions rarely go beyond an easy commuting distance from the city (Carson et al., 2020). Furthermore, day tours from urban areas reduce the time and money spent in rural areas and affect the potential for sustainable development of tourism in rural regions. Tourism in rural regions is also often highly seasonal and is characterised by an uneven distribution of visitors, resulting in uneven distribution of revenues and potential economic leakage from rural areas to a dominant centre (Huijbens, 2022; Maher et al., 2022; Rantala et al., 2019).

2.4 Seasonality and Sustainable Tourism Management

Seasonality in tourism is one of the greatest challenges for tourism management as it has diverse impacts. Tourism seasonality is usually defined in negative terms as it creates temporal and spatial imbalances that are observed in the tourist flow during the year (Connell et al., 2015; Duro, 2016). This seasonal imbalance affects occupation stability in the tourism field, which has various impacts on the local community (Rantala et al., 2019). Therefore, tourism authorities develop their policies with the aim to minimize the seasonal imbalance (Mihalic et al., 2021).

Several attempts have been made in the tourism literature to define seasonality, but as stated by Butler and Mao (1997), seasonality is a complicated phenomenon that involves physical, economic, and social variables in both the region of origin and the destination region. Seasonality is often split into two different categories: natural and institutional seasonality (Bar-On, 1975; Butler, 1994; Hartmann, 1986). *Natural* seasonality is linked to temporal variations in the weather over the course of the year. The weather is both a push and a pull factor and has a major influence on decisions to travel; for example, travellers decide where to go based on whether they want to sunbathe, hike, or ski, among other activities (Butler, 2001). Unstable weather and darkness is also a pull factor (Heimtun, 2015) and can add special excitement to the journey and make the destination interesting (Heimtun, 2015; Lundtorp et al., 2001). *Institutionalised* seasonality refers to the combination of different traditions, for example, religion, culture, and religious and school holidays. Public holidays such as Easter, Whitsun, and Christmas as well as special events can shape their own seasons with an increase in the number of visitors to a destination (Lundtorp, 2001).

A wide range of measures has been used to analyse seasonal variation in tourism (Paper 1). The basic unit used to measure seasonality is the number of visitors. The analyses are usually made from overnight stay data or arrivals/departure data using days, weeks, or months (Lundtorp, 2001). From this data the seasonality in overnight stays can be determined. Often such information is enough, but for regions that are characterised by one strong core that dominate the mobility patterns into the rural areas, more relevant data, such as visitor numbers at nature-based destinations, is also needed to accurately portray the spatial impact of tourism mobility (Paper 1).

According to Koenig-Lewis and Bischoff (2005), the most used tools to analyse tourist seasonality are: coefficient of variation, seasonality ratio, and the Gini coefficient. All these tools have strengths and weaknesses. Both the seasonality ratio and the seasonality indicator are sensitive to the highest value. The Gini coefficient is the most used tool to analyse seasonality (Papers 1 and 3; (Duro, 2016), and although it is not as sensitive to the highest value as the seasonality indicator, it is more sensitive to variations outside the peak season. Based on these properties linked to seasonality, this study uses the Gini coefficient to analyse seasonality between sites.

2.5 Nature-Based Tourism in the Arctic

Nature-based tourism has been increasing during the last decades. While the academic literature offers various definitions of nature-based tourism, this study uses Fredman and Margaryan (2021, p. 15) definition of nature-based tourism: 'activities by humans occurring when visiting nature areas outside the person's ordinary neighbourhood'. The term 'nature-based tourism' covers a wide range and many different activities, such as wilderness tourism, adventure tourism, wildlife tourism, and ecotourism (Fredman & Margaryan, 2021).

Arctic tourism has been growing rapidly and is, as elsewhere, considered a significant economic opportunity. As previously noted, the attraction of the Arctic is most often its nature and nature-based tourism destinations. Arctic tourism largely revolves around guided activities that do not require any special skills, such as dog sledging, snow mobile trips, and visits to see the Aurora Borealis. In Iceland, taking short hikes to glaciers is also popular among foreign visitors. This activity is accessible because the outlet glaciers are close to the main road in the south (Welling & Arnason, 2016). The Arctic is also advertised as a winter wonderland where no one lives and is thus waiting to be discovered by visitors (Rantala et al., 2019). Despite this projected sense of isolation, the Arctic offers certain key attractions, and therefore, the visitors are seldom alone.

Koster and Carson (2019) discuss the 'boring bits in-between', and such areas are located in between urban core areas and iconic peripheral destinations or resort towns. The characteristics of such sites is a lack of outstanding natural or cultural attractions that draw visitors to visit them (Paper 3; (Lundmark & Carson, 2020). While the 'boring bits' might have plentiful scenic nature, they do not stand out or offer a similar experience that can be gained closer to an urban core. The geographical location of a site can therefore be a reason for the site to be less visited than other similar ones, but this aspect is also impacted by the transportation system; the infrastructure, for example, accommodation; and the length of stay in the region (Müller et al., 2020).

2.6 Mobility Measures

Researchers have used several methods to analyse the mobility patterns of tourists. Traditional methods for mobility analysis include interviews, surveys, and direct observations. These methods are often time consuming and expensive in practice, not the least in rural and peripheral areas where there are few people to participate (Orellana et al., 2012). The field of tourist tracking research is expanding rapidly, and geo-tagged applications, GPS technology, mobile phone data, and credit card data are serving an increasingly prominent role. These tools are becoming essential in tourism research, marking a significant and swiftly growing area within the field (Bishop et al., 2024; Hardy, 2020b; Sveinsdóttir et al., 2025). Furthermore, big data in tourism mobility research is derived from Internet searches, bank transactions, mobile phone records, social media activity to name few prominent sources. Tourists leave their digital footprints through many of their activities, which enables researchers to analyse their mobility patterns (Salas-Olmedo et al., 2018). These big data sources provide a vast amount of information that can complement traditional sources.

In recent years, researchers have also recognized opportunities in using new methods to analyse tourism mobilities derived from big data sources. This data is derived, for example, from mobile devices, social media, Flickr, Instagram, and Twitter (Bishop et al., 2024; Fisher et al., 2018); Bluetooth/Wi-Fi sensors at airports (Bullock et al., 2010; Gheorghiu et al., 2021); and in urban environments in city centres and at museums (Versichele et al., 2014; Yoshimura et al., 2017). Mobile phones have also been used for this purpose (Warnken & Blumenstein, 2014) as well as GPS detectors. These methods all have their strengths and weaknesses, and the most acceptable method that is practical and within the financial limits of the project needs to be determined for each site or region (Cessford & Burns, 2008). Therefore, data from smart devices and social media is becoming considerably important for peripheral rural areas, like the ones in the Arctic that lack staff and financial capacity to manually collect data to analyse tourism mobility (Runge et al., 2020).

Data from big data sources provide researchers with a vast amount of data on visitor movements, and such information provides researchers with insights about visitor flow, traffic, and crowding. Despite these benefits, certain methodological issues need to be kept in mind when using these techniques, and validating the integrity and the consistency of big data analytics is crucial (Hardy, 2020b). In the case of transport analytics, the data should be validated against an existing data set that has been confirmed for accuracy, for example, data from vehicle counters or trail counters (Streetlight, 2019).

In recent years the use of artificial intelligence has been increasing. Yuen et al., 2023 successfully developed an artificial intelligence enabled contactless visitors access monitoring system with a facial recognition system and real-time database. Artificial intelligence has also been used to automatically analyse data from camera traps. Before the number of visitors had to be counted manually from the photos but now the artificial intelligence can automatically count the number of people in photos and describe their activities (Guidosse et al., 2025). These new methods are important, but they also need to be used with care and respect for the person being recorded and analysed. Using material from these big data sources raises several ethical questions about the data source, as the data is often collected without the consent of the individual (Hardy, 2020b). Therefore, ethical considerations are crucial when working with this kind of tracking data, and researchers need to make sure that the data cannot be traced to the individual (Hardy, 2020a). Collecting data without individuals' prior consent has advantages as well as disadvantages. Since the individual has no knowledge about their participation in research, this aspect does not influence their travel as can happen when the individual knows about being a part of a research project. The awareness of being part of a research project may bias the results. However, the data provides no socio-demographic data, nor data on tourists' preferences. Therefore, differentiating between locals and tourists is hard or even impossible. As this context may be considered a disadvantage, it is also an advantage as the lack of socio-demographic data makes the dataset less traceable (Hardy, 2020c).

Mobile phones can also be used for analysing tourist mobility and their numbers within a destination. Cell phones have their own ID number that is continually being tracked by the nearest transmitting base station to give the phone the best connection. The position of the mobile phone is determined with 50–100 m accuracy, depending on the density and number of available base stations. The density and number of base stations are the key factors when mobile phones are used to analyse the number of visitors and their distribution (Warnken & Blumenstein, 2014). Bauder (2015) considers the mobile phone poorly suited for analysis of tourists' mobility patterns as too many gaps occur when the phone moves between transmitters. However, the mobile phone technology could hypothetically provide useful information about how visitors move within a certain space (Warnken & Blumenstein, 2014).

Despite the benefits of using big data, collecting data from mobile phones without the consent of their owners is illegal in many countries because of privacy considerations (Warnken & Blumenstein, 2014). Therefore, the privacy conditions need to be ethically considered when using both mobile phone and social media data (Fisher et al., 2018).

3 Methodology

3.1 Methods

As the focus of the research was on developing and testing methods to analyse tourism mobility patterns the methods have been thoroughly explained in the research papers. Therefore, I will not explain the methods in detail and will only give a short overview of the research development.

In 2014, I was working on a project at eight popular nature-based destinations in south and west Iceland (Ólafsson & Thórhallsdóttir, 2015), and one part of this project concerned counting visitors at these sites. During this time, tourism was increasing greatly, and tourism authorities recognized the importance of knowing the mobility patterns of visitors in time and space to manage tourism sustainably. They were highly concerned about distributing regional revenues as well as protecting Iceland's main tourism attraction, nature. In 2014, most of the operational counters were within Vatnajökull National Park as well as in the southern part of the central highland, and they were set up in connection with an older research project. At this time, one of my supervisors, Rögnvaldur Ólafsson, was responsible for all the counters.

In 2015, the Tourism Task Force was established and remained in force until 2020. The aim of the task force was to create a basis for an efficient tourism policy in Iceland, founded on sustainable tourism management. The task force was designed to facilitate collaboration among diverse stakeholders, including members from different ministries, representatives from municipalities, and the private sector. It focused on seven key priorities: coordination, positive experience of tourists, reliable data, the protection of nature, competence and quality improvement, increasing revenue, and tourist distribution (The Ministry of Industries and Innovation, 2015). At this point in time, 2015, I recognized the opportunity to use the data on visitor numbers at important nature-based destinations to analyse the mobility patterns of visitors in time and space. To do that, I needed more counters. The Tourism Task Force also saw the opportunity to add counters because of their aims. Therefore, during the summers of 2016 and 2017 many counters were subsequently added to the net of counters at various nature-based destinations.

In 2017, I published my first paper (see Section 4.1) where I used six nature-based destinations in south and west Iceland to explain the methods behind the work of using vehicle counters to compute visitor numbers. In 2021 I published my second paper (see Section 4.2). In Paper 2 I tested the use of a radar to collect the information on vehicle types. Therefore, in Papers 1 and 2, I tested the methodology of using vehicle counters at nature-based destinations to compute visitor numbers that could be used to analyse tourism mobility patterns in Iceland.

I published Paper 3 in 2024, and for this study I used the data from the nature-based destinations to analyse the mobility patterns in time and space in Iceland (see Section 4.3). From 2014 to 2017, I met many people from municipalities as well as staff members from the Tourism Task Force, and the pressing topic was how the number of visitors was increasing exponentially and how little was known about their mobility patterns and travel behaviour. For sustainable tourism planning and management, the time spent in a region is considerably important, and I wanted to measure this aspect automatically, not with questionnaires or interviews requiring extensive on-site fieldwork. Therefore, I acquired and tested Bluetooth sensors in a few locations before I had the opportunity to set them up in the Jökulsárlón area (Ólafsson et al., 2017). For my project, this situation was interesting as I could also analyse the direction of travel, in other words, from where the visitors came and to where they continued. The Jökulsárlón area was selected for several reasons, including the interest of the municipal government of Hornafjörður to use this data for infrastructure planning. Moreover, during this time, in late 2017 Vatnajökull National Park was updating their management plan following the addition of Jökulsárlón and its vicinity to the park. This area offered an advantageous location to test the research method as in this region I could both analyse the regional mobility as well as draw insights about national mobility pattern. In this area there are no side roads leading to other regions, only road number one around Iceland. I also received assistance from the rangers of Vatnajökull National Park in maintaining the batteries for the sensors. The batteries needed to be changed nearly every 10 days, but during the last phase of the data collection, we attempted to use solar cells, which provided suitable results.

3.2 Study Sites

The research area is Iceland and its most visited nature-based destinations, which are depicted in Figure 3. The vehicle counters were either used to compute numbers of visitors or to compare their data to other datasets, the radar or the Bluetooth sensors. In Landmannalaugar I tested a radar to calibrate vehicle counters; both for errors in the counting but also to determine between vehicle types. In the Jökulsárlón area I tested Bluetooth sensors to analyse the direction of the travel but also to compute the average length of stay in the area. The vehicle counters, the radar, and Bluetooth sensors were set up at the study sites in relation to various projects I participated in during the years 2014 to 2017.

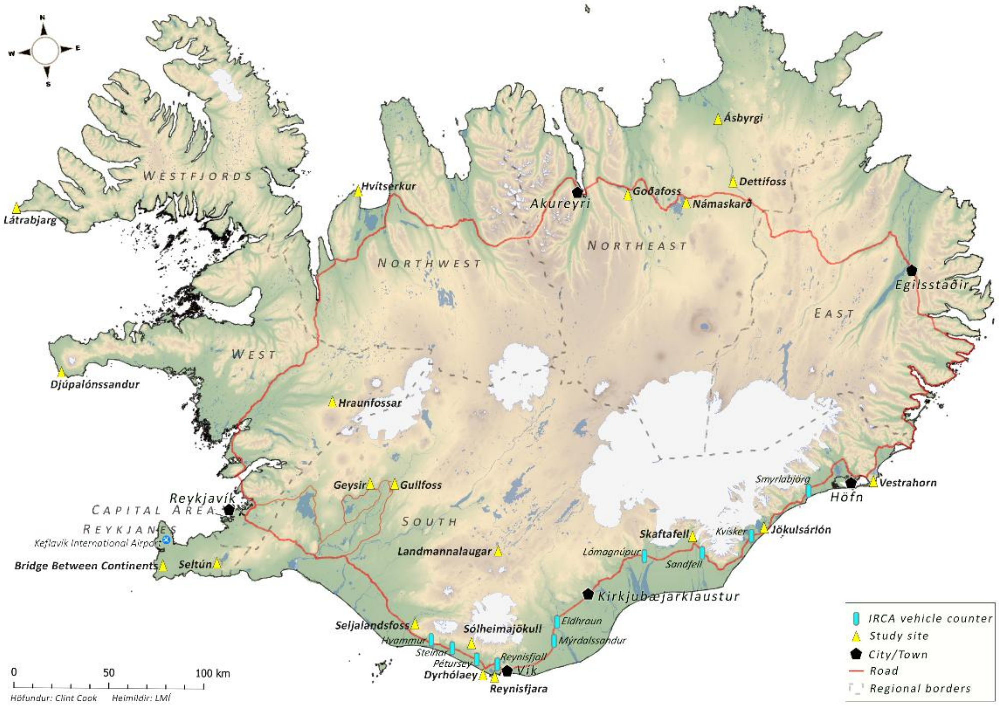

Figure 3. The Study Sites

3.3 Research Approach

To understand the mobility patterns of visitors in time and space, the study uses a positivist approach. Positivism originates from the 19th century, and it arose from the founder of sociology, the Frenchman, Auguste Comte. Later thinkers, for example, Émile Durkheim, John Stuart Mill, and others expanded on positivist principles, applying them to sociology and philosophy. Positivist research dominated the social research journals in Scandinavia, Britain, Canada, and the United States during the 1960s and 1970s (Neuman, 2014).

Many versions of positivism exist, and the term has been widely defined, but overall positivism emphasises empirical evidence and the scientific method, which leads to research that is systematic, replicable, and objective. This approach has been essential in natural sciences and allows for clear, measurable, and testable outcomes (Benton & Craib, 2023). Positivism focuses on quantifiable data and is particularly useful for large-scale studies and statistical analyses. This approach is valuable for generalizing and identifying patterns or trends in data across various fields (Neuman, 2014).

This research tests a methodology for analysing the mobility patterns of tourists in time and space. I use quantitative data to compare the sites as well as to verify the method at individual sites. The data is testable and the error at each individual site is known from the calibration factor. Positivist research is structured and standardised, and often, it follows strict methodological rules, which can ensure clarity and consistency in the research process.

When I started this procedure, I had to structure the methodology follow certain rules as explained in Papers 1, 2, and 4. Therefore, a positivist approach is relevant to my research. Positivist data is useful for informing policy decisions, social planning, or industrial and technological development. In this study, I use the data to analyse tourism mobility and compare the results to the tourism policy in Iceland and the aims of sustainable tourism management to analyse how successful this policy has been.

Even though a positivist approach is appropriate for empirical research that requires measurable and testable outcomes, it has also received a negative label in certain academic and philosophical circles, particularly for its limitations in understanding complex social phenomena. The critique has mostly been on its reductionism, which oversimplifies human experiences, but also on its emphasis on objectivity that often ignores values and context (Benton & Craib, 2023). Given the aims, methods, and data sources of this specific study, I do not consider that such critiques impact my work to any significant extent.

4 Summary of Papers

This Ph.D. thesis consists of four peer-reviewed publications. The following sub-sections summarise the content of each paper. Three papers have already been published, and one has been submitted for review.

4.1 Paper 1

Title
A method to analyse seasonality in the distribution of tourists in Iceland.

Abstract
Iceland has enjoyed increased popularity among tourists during the last few years. In 2010, 459 thousand visitors came to Iceland but in 2015 about 1,3 million visited the country. Before 2010 seasonality was high but has decreased since. This is reflected in the changing amount of overnight stays in the capital area. The same has not happened in other regions of the country where seasonality is still high. It seems that during the off-peak season the visitors are overnighting in the capital region and taking day tours to destinations in South and West Iceland. Overnight stay data does therefore not give complete picture of travel behaviour and how tourists distribute around the country. Therefore, a new approach is needed.

The paper describes a method that analyses seasonality in the number of tourists at nature destinations in South and West Iceland. The data is obtained from vehicle counters. Seasonality at the destinations is then expressed numerically by computing the Gini coefficient. Finally, the Gini coefficients are compared for the destinations, regional overnight stays and departures from Keflavík International Airport. The paper provides a methodological approach to analyse seasonality and the distribution of tourists in an efficient manner.

Objectives
The main objective of this paper was to analyse the research method when vehicle counters at nature-based destinations are used to determine where tourists go in time and space. The dataset from the nature-based destinations was then compared to a dataset on overnight stays collected by Statistics Iceland.

Study Area
Six nature-based destinations in south and west Iceland.

Methods
Paper 1 describes the methodology of computing the number of visitors from the number of vehicles. This study uses the Gini coefficient to analyse seasonality at the nature-based

destinations. Paper 1 also tested if computing the Gini coefficient from daily, weekly, or monthly data resulted in any differences.

Main Results
The main results of Paper 1 were that overnight stay data provides useful information about where the visitors stay overnight, but the dataset does not give any information about where the visitors go during the day. This information is important to determine as tourists in Iceland mainly come to experience nature, and these day-trip locations cannot be determined by the overnight stay data. Therefore, the research should further assess visitor counting at the nature-based destinations. This data is crucial for tourism authorities when making a comprehensive management plan for the country and for infrastructure development.

Status
Published in *Journal of Outdoor Recreation and Tourism*.

Thórhallsdóttir, G., & Ólafsson, R. (2017). A method to analyse seasonality in the distribution of tourists in Iceland. *Journal of Outdoor Recreation and Tourism*, *19*, 17-24. https://doi.org/http://dx.doi.org/10.1016/j.jort.2017.05.001

4.2 Paper 2

Title
A methodology of estimating visitor numbers at an Icelandic destination using a vehicle counter and a radar.

Abstract
Knowing the number of visitors to a destination is a basic requirement for the management of visitor services, experiences and impacts. This paper is a part of a long-term study that uses vehicle counters to compute visitor numbers at several Icelandic nature-based tourist destinations. All counters need to be calibrated for errors in the counting. Furthermore, when data on vehicle numbers are used to compute visitor numbers it is important to collect additional data. The counters cannot distinguish between direction, nor the size of the vehicle. Therefore, it is important to collect additional data on the ratio between private cars and buses, as buses carry far more people than private cars. Both the calibration of the counters and the length estimates have traditionally been done manually, which is time consuming and expensive. This paper describes an automatic method, using a microwave radar, to calibrate the counters and measure the length of the vehicles at the same time, making it easy to find the ratio between private cars and buses. As far as the authors know, a microwave radar has not been used for this purpose before. The reliability of the radar to calibrate the vehicle counters and measure the length of the vehicles was computed. The findings indicate that using radar to calibrate the counters is more reliable and economical than the traditional manual calibration.

Objectives
The aim of the research was to simplify the process of obtaining data from vehicle counters, data that could be used to compute reliable data on number of visitors. A radar, that measures

the length of the vehicle was used to count the number of buses in Landmannalaugar to find the ratio between buses and private cars. That is important to know the average occupancy in a vehicle.

Study Area
Landmannalaugar in the southern part of the central highland.

Methods
Vehicle counters and a radar were used to collect data on visitor numbers.

Main Results
The findings indicate that using a radar to calibrate vehicle counters is more reliable and economical than the traditional manual calibration. The radar needs to be carefully set up and tested for a few hours to determine if it is counting in accordance with the traffic.

Status
Published in *Journal of Outdoor Recreation and Tourism*.

Thórhallsdóttir, G., Ólafsson, R., & Jóhannesson, G. T. (2021). A methodology of estimating visitor numbers at an Icelandic destination using a vehicle counter and a radar. *Journal of Outdoor Recreation and Tourism, 35,* 100378. https://doi.org/https://doi.org/10.1016/j.jort.2021.100378

4.3 Paper 3

Title
Mobility Patterns and Sustainable Tourism: Planning and Managing Tourism in Iceland

Abstract
Tourism in Iceland has experienced significant changes in the past decade. Visitor numbers increased from 459,000 in 2010 to 2.3 million in 2018. However, there was a 14% decrease in visitor numbers between 2018 and 2019, and in 2020, the visitor numbers collapsed because of the COVID-19 pandemic. The effect of the pandemic started to decrease in spring 2022 as visitors returned.

The great increase from 2010 to 2018 prompted Icelandic authorities to focus on sustainable tourism management in their policymaking. The focus has been on distributing the flow of visitors and associated revenues more evenly across regions, while protecting the main tourist attraction: nature, as well as nature-based destinations. Knowledge of mobility patterns at different scales is crucial for the sustainable development and management of tourism. This study analyses mobility patterns in Iceland through examining visitor numbers at 18 nature-based destinations scattered around the country. The mobility patterns are then related to the sustainable tourism objectives of the Icelandic tourism authorities.

The results indicate that the south and southwest region of Iceland is more visited and exhibits less seasonality than other regions of the country. Seasonality has decreased in all regions but not to the same extent as in the south and southwest, the area that includes both the main gateway, Keflavík International Airport, and the capital city of Reykjavík, which often serves as a basecamp for natural attractions. When planning for and managing sustainable tourism in Iceland, it is crucial to know the number of visitors at nature-based destinations, as these numbers are key for analysing mobility patterns.

Objectives
The aim of Paper 3 was to analyse the mobility patterns of international visitors in time and space in relation to the aim of the Icelandic tourism authorities to sustainably manage tourism in the future.

Study Area
Paper 3 assessed 18 nature-based destinations in Iceland.

Methods
The study determined the number of visitors at 18 nature-based destinations. The data was derived from vehicle counters and a border survey.

Results
The mobility pattern on international visitors in Iceland moves from the main gateway in southwest Iceland, Keflavík International Airport, towards the east. The nature-based destinations on the Golden Circle travel route are the most visited, as well as the ones along the South Coast travel route, ending at Jökulsárlón. Seasonality in these regions is also much lower than elsewhere in the country.

Status
Published in *Journal of Arctic Tourism*.

Thórhallsdóttir, G., Ólafsson, R., Jóhannesson, G. T., Árnason, T., & Gudmundsson, R. (2024). Mobility Patterns and Sustainable Tourism: Planning and Managing Tourism in Iceland. *Journal of Arctic Tourism*, *2*(1), 15-26. https://doi.org/https://doi.org/10.33112/arctour.2.2

4.4 Paper 4

Title
Sustainable Tourism Planning and Management - A Method to Analyse Mobility Patterns in Time and Space - A Case Study from Southeast Iceland.

Abstract
The aim of the paper is to test and evaluate an innovative research method for analysing tourism mobility patterns in rural peripheral areas. The mobility patterns relate to the management of services, such as transportation and diverse infrastructure, that is important for sustainable tourism planning and management. Two sensors that detect Bluetooth signals from smart devices were strategically positioned east and west of the glacial lagoon Jökulsárlón, a popular nature-based destination located in Iceland's rural southeast. The

method gives insights into visitor flow, traffic, crowding and sequential movement. It offers an economic means of gathering extensive data on tourism mobility in rural areas that can inform for sustainable tourism planning and management.

The study identified seasonality in mobility patterns in the area. The visitors stayed on average two hours in the area, longer during the winter. During the winter the mobility patterns were characterized by the west to east movement followed by a return flow westward. During the summer, the west to east movement was dominant, indicating that the visitors were driving around the island. The research method and its results are important for managers of rural peripheral sites when planning for sustainable tourism.

Objectives
The aim of Paper 4 was to test and evaluate an innovative research method for analysing tourism mobility patterns in rural peripheral areas in relation to sustainable tourism planning and management.

Study Area
Paper 4 assessed the area around the glacial lagoon, Jökulsárlón, in southeast Iceland.

Methods
Two Bluetooth sensors were set up west and east of Jökulsárlón. The sensors detect signals from smart devices, such as mobile phones. Therefore, if a signal from a smart device was detected at the sensors, the mobility pattern of the 'device' could be analysed. The average length of stay in the area was also computed from the sensors.

Results
The main finding of Paper 4 is that international visitors travel from the southwest to Jökulsárlón. During the summer, they seem to be driving around the 'Ring' (i.e., Highway No. 1 or the Ring Road), which circles around Iceland, but during the winter, Jökulsárlón is the end destination from which they return. The average length of stay was around two hours and was longer during the winter than the summer. These results indicate the importance of the core in the southwest, from which the flow of international visitors starts and moves mostly towards the south, ending at Jökulsárlón. This trend goes against the sustainability aims of the Icelandic tourism authorities who prefer a more even distribution of tourism in all regions of the country. Therefore, future research should consider if the sustainability aims of the Icelandic tourism authorities—to distribute the flow of tourists more outside of the popular areas—is a viable solution for sustainable tourism management or not.

Status
The manuscript is in handout.

Thórhallsdóttir, G. (Handout). Sustainable Tourism Planning and Management - A Method to Analyse Mobility Patterns in Time and Space. *?*, *?*(?), ?-? https://doi.org/?

5 Discussions and Conclusions

This doctoral thesis summarises my previous research, detailed in Papers 1–4, and this literature review explains how I tested a multi-layered research method to analyse tourism mobility patterns in areas where the mobility patterns move from a strong core into rural peripheral areas. The research method is assumed to be valuable for regions with similar mobility patterns as Iceland, such as the Arctic regions. In these regions, the mobility patterns are characterized by a strong core from where visitors drive out in the morning and return back in the evening.

At least since 1996, Icelandic tourism authorities have promoted sustainable tourism planning and management, and one of their main aims has been to distribute the flow of international visitors beyond the popular destinations. Despite this goal, the results of the study show that specific sites along the South Coast and the uplands of the south were most visited. Other regions were less visited, and they also exhibited higher seasonality (Paper 3). Compared to other regions in Iceland, the south has a geographical advantage because of its proximity to the main gateway to Iceland, Keflavík International Airport, and the capital area in the southwest. Moreover, along the South Coast is a chain of unique and interesting nature-based destinations that benefit from being between the strong core in the southwest and the unique nature-based destination, Jökulsárlón in the southeast. Furthermore, the nature-based destinations along the two travel routes in the south, the Golden Circle and the South Coast, are unique and provide multiple experiences, including a geothermal area, an erupting hot spring, various types of waterfalls, a black sand beach, multiple glaciers, and a large glacial lagoon, among others. The other regions might have similar sites, such as powerful waterfalls and geothermal areas, but the travel distance from the southwest is often greater, and no other region has a glacial lagoon, nor the same diversity of attractions along the travel route, as the south. In a study among German car tourists in Sweden Zillinger (2007) found that they followed a discernible mobility rhythm that was not only shaped by the tourist attractions but also by the proximity of these attractions to other sites, the distance from the tourists' residences, and the duration of the tourists' stays in Sweden.

Therefore, the reason for the flow towards the south is most likely explained by concepts such as distance decay, access, uniqueness of the attractions, and time geography. According to the distance decay theory, the more distant and less accessible destinations are inevitably less frequented unless they manage to provide the scale, quality, and uniqueness required to overcome distance (Prideaux, 2002), such as Jökulsárlón does. Time geography describes behaviour in time and space (Grinberger et al., 2014). This study highlights the relationship between time, space, and mobility as reflected in the seasonality of various sites in Iceland. The limited time visitors have during their holidays also influences the distance they can travel. In the summer, when tourists have more time, they tend to stay longer in the country and explore regions further from Keflavík International Airport. They are also more likely to drive around the Ring Road that encircles Iceland. Paper 4 illustrates further how spatial mobility is dependent on time. During the summer, the average length of stay in the country was longer than during the winter. However, during the summer, the visitors also stayed for a shorter period of time at Jökulsárlón than during the winter. This trend could be attributed to the desire to participate in the primary winter activity at this site: ice cave tours (Árnason & Welling, 2019). These tours last 3–4 hours, and during shorter winter holidays, visitors may need to be more selective, opting for the most unique and interesting sites available, given their constraints. As a result, they might spend more time at each location in winter than in summer when they are more likely to be travelling around the entire island.

5.1 The Value of the Research Method for Analysing Tourism Mobility Patterns

This section answers Research Question 1: *How are the research methods valuable for analysing tourism mobility in regions characterised by a strong core from which the flow of tourism is towards peripheral rural areas?*

The number of visitors at any given destination can be gauged in several ways. The most appropriate method needs to be found for each destination, and the financial limits of the project must also be considered (Cessford & Burns, 2008). Big data sources are currently being used to estimate the number of visitors. Using multiple datasets to analyse tourism mobility patterns allows researchers to generate a more detailed and often more nuanced understanding of tourism trends. This study analysed the mobility patterns from overnight stay data, data on the number of visitors and vehicles at nature-based destinations, data on the number of vehicles along the south coast, and departure data from Keflavík International Airport. The study also used data on travel direction and computed the average length of stay in the area around the nature site Jökulsárlón. This research provides basic information about the mobility patterns in Iceland.

This approach is linked to both strengths and weaknesses. The advantage of using multiple datasets that give the same or similar results allows more confident conclusions to be drawn. The data on the number of departing visitors from the main gateway Keflavík International Airport are valuable for analysing the mobility patterns as this information is considered the starting point. Likewise, the overnight stay data shows that visitors tend to stay in the capital area, especially during the winter. However, the overnight stay dataset cannot inform where the visitors go during the day. To have an accurate understanding of tourism trends, policy makers should know where the visitors stay overnight and where they go during the day (Runge et al., 2020). In this research, I have demonstrated both of these aspects, and together, these datasets provide valuable information about mobility patterns in Iceland.

These datasets show the importance of the south for tourism in Iceland. The Bluetooth sensors that I used to analyse the regional direction of mobility patterns in southeast Iceland gave the same results as the other datasets. Therefore, I conclude that the research method that consists of different datasets is valuable and gives useful information about the mobility patterns in regions where the mobility pattern is dominated by a strong core from where the flow is towards the peripheral rural areas.

5.2 The Relationship Between Mobility Patterns in Iceland and the Aim of the Icelandic Tourism Authorities to Plan and Manage Sustainable Tourism

This section answers Research Question 2: *How do the mobility patterns in Iceland relate to the Icelandic tourism authorities' aims to better plan and manage sustainable tourism?*

The Icelandic tourism authorities emphasise reducing regional seasonality by distributing the flow of visitors outside of the popular areas to reduce uneven regional distribution of revenues derived from tourism. Despite this goal, regional seasonality remains high outside of the south and southwest regions, and the tourist flow is still predominantly towards the south. Seasonality has decreased in every region, and the number of visitors to other regions has also increased, but the increase is much higher in the south (Paper 3). The reasons for the dominant mobility patterns from the southwest towards the southeast are diverse. First, the dominant gateway and the capital area are located in the southwest. Second, the unpredictable weather creates a challenge when travelling from the dominant gateway in the southwest, and during the winter, the transportation system can be unreliable because of wind, snow, and ice, especially on mountain roads. During the winter, the access roads to nature-sites in the north and in the Westfjords may not be serviced by the road administration.

The findings do not offer a concrete answer as to whether the Icelandic tourism authorities should continue to distribute the flow of foreign visitors outside of the popular areas to improve sustainable tourism management. The financial resources of the tourism authorities are not unlimited, and some highly visited sites need investment in infrastructure, and appropriate infrastructure is also a matter of safety. Developing other, less popular sites would require significant investment in infrastructure and services, without any guarantee that such investments would serve their intended purpose.

Iceland's sub-arctic flora is vulnerable to environmental degradation due to overcrowding and trampling. Therefore, a relatively low number of visitors may induce high impact (Jóhannesson et al., 2010; Ólafsdóttir & Runnström, 2013; Sæþórsdóttir, 2014). Within the tourism policy's environmental framework, an emphasis is set on a balance between the exploitation and protection of nature, and the importance of infrastructure development taking this into account. Also, regulations are expected to support a healthy work environment, promote fair competition, ensure social responsibility, and foster sustainability, profitability, and value creation in tourism (Government of Iceland, 2024).

Tourism today faces a significant challenge as its reliance on continual growth conflicts with sustainability objectives. Although sustainable tourism has been a topic of discussion for over thirty years, tourism authorities still prioritize expansion, overlooking the ecological and social boundaries of our finite planet (Higgins-Desbiolles, 2018). For sustainable tourism management, the rights of local communities need to be put above tourists and tourism companies to make profit (Higgins-Desbiolles et al., 2019).

The degrowth concept is sometimes associated with downscaling but it is better understood in terms of rightsizing an economy so it can achieve a better balance between resource and supply (Hall & Wood, 2021). Therefore, it can be said that determining the optimal number of visitors for nature-based destinations is a critical step toward this goal. The data collected in this study may serve as a foundational resource for establishing visitor capacity thresholds.

The practical implications of this study are highly significant for sustainable tourism planning and management in destinations such as Iceland. The findings offer crucial insights for identifying the essential services and infrastructure needed at nature-based destinations. Additionally, the results shed light on regional seasonality, which, along with visitor data, plays a critical role in sustainable tourism planning and management (Lew & McKercher, 2006). Furthermore, the insights gained from this study are beneficial for tourism management beyond Iceland, especially in Arctic regions where nature-based attractions are prominent, and challenges such as high seasonality and uneven regional distribution of visitors and revenues are prevalent.

5.3 Visitor Numbers at Nature-based Destinations and Sustainable Tourism Planning and Management

This section answers Research Question 3: *How does the analysis of visitor numbers at nature-based destinations contribute to the planning and management of sustainable tourism in similar regions, such as the Arctic regions?*

Analysing visitor numbers is one approach to analyse tourism mobility patterns, and it also measures the mobility patterns during the day when the visitors are actively travelling to and between different sites. This approach is important for core/peripheral destinations and management for sustainable tourism. In Iceland and in other Arctic countries, nature and nature-based destinations are the main tourist attractions. Sustainable tourism management requires knowing the number of visitors that visit each given attraction and the changes occurring in these places between years. This information is important to protect nature and to manage infrastructure at the sites and the transportation system that connects them. Knowing the number of visitors to a destination is a basic requirement for the management of visitor services, experiences, and impacts (Cessford & Burns, 2008).

Developing infrastructure both at the regional level and at individual sites is expensive. Paper 1 explains that the transportation system in Iceland has been insufficiently funded since the economic crisis in 2008 and is becoming, with increased tourism, dangerous in some parts. This discussion continued in 2024, although parts of the Ring Road in all regions have been improved greatly. Even though the road system in Iceland has improved, the weather continues to be unpredictable and often extreme, and the roads and the access roads to the sites can close during the winter because of snow and ice as well as strong winds. Moreover, most of the international visitors use a rental car while travelling in Iceland, and that trend creates a strain on the transportation system and the road authorities, especially during the winter. Therefore, concentrating on developing robust infrastructure for year-round tourism in the southern regions may be more sustainable for Iceland, rather than spreading such efforts across the entire country and thus delaying improvements where they are most needed. Runge et al. (2020) suggest that guiding visitors toward specific areas or sites, rather than allowing unrestricted access, could also help protect the fragile Arctic vegetation and wildlife.

The findings suggest that Keflavík International Airport plays a crucial role in influencing the spatial distribution of tourists in Iceland. Shifting this pattern would necessitate the enhancement of other entry points, such as Akureyri in the north and Egilsstaðir in the east. Several attempts have been made to launch international flights from Akureyri Airport in northern Iceland, all of which have been unsuccessful. This outcome suggests that for such flights to be commercially viable, the local market alone is insufficient. In October 2023, EasyJet began offering flights to Akureyri Airport from London Gatwick (Daðason, 2023).

While strengthening these airports could have an impact on the mobility patterns of visitors, it raises the question of whether the attractions in the north and east are compelling enough to draw significant visitor numbers, even with shorter travel distances. Furthermore, the appeal of the natural sites in the south and the proximity to Reykjavík, Iceland's only city, with its wide range of cultural and social offerings. However, the fact that a well-established international airline, such as EasyJet, recognizes potential in scheduling flights to northern Iceland indicates that further development of attractions in the region is likely, which could alter tourist mobility patterns to some extent. Nonetheless, developing other sites would require significant investment in infrastructure and services. Therefore, future research should consider whether redistributing visitor flows should continue to be a primary focus of Icelandic tourism management.

5.4 Final Remarks and Future Research

The research has various limitations. Using only descriptive data to analyse tourism mobility could be considered a limitation, as the human experience is left out of the study frame. The aim of the study, however, was not to analyse the experience or motivation of visitors but rather to develop and test a multi-layered method to quantitatively analyse tourists' actual mobility patterns. These two approaches are not mutually exclusive, and both need to be applied to provide full knowledge about both mobility patterns and their causes. This approach is rarely done, however, at least on a nation-wide scale, despite the fact that related, usable data is routinely collected by national or regional tourism authorities. The scope of this study focuses on how to use these existing data sources, as well as new ones, to better provide empirical data for the sites that are visited by tourists, as well as how these might be connected one to another.

The data is important for planning and managing tourism at individual sites as well as in cases when the sites are connected to provide predictions on mobility patterns. The vehicle counters are reliable regarding the number of vehicles, as explained in Paper 2. Furthermore, computing vehicles to visitors is complex, time consuming, and expensive (Papers 1 and 2).

The aim of the study was to test research methods to analyse tourism mobility patterns. I wanted to determine if it was possible analyse tourism mobility patterns from nature-based destinations. To obtain the best results on visitor numbers, data on the ratio between buses and private cars needed to be collected for each site as well as the average occupancy of each type of vehicle. Buses are of many sizes, making the average occupancy in a bus variable between sites. Some sites have higher average occupancy than others. Collecting the data that was described in Paper 1 for all sites is not realistic. This process was only possible because two projects were run simultaneously, and the staff could work on both projects. Moreover, this occupancy number can change with time. Therefore, the number of visitors based on vehicle counters is only an estimate, but the dataset is still relevant in mobility research. When combined with the overnight stay data, we obtained information about where people stay overnight and where they go during the day. Together, these two datasets benefit each other, especially where the core is as strong as in Iceland. Currently, information is available about where visitors overnight but also where they go during the day.

The Bluetooth sensors, as well as other big data sources, provided a vast amount of data to analyse tourism mobility. The direction of the travel is now known, but as with the vehicle counters, it cannot be observed who is travelling, visitors or locals. Limitations with the dataset also presents limitations, and assumptions had to be made from the dataset. Local traffic was thus assumed to be those travelling from east to west and staying for at least six hours. I also assumed that those who were travelling from the west were coming from the southwest, the capital area or Keflavík International Airport. Following people’s travels around the island would be interesting for future research. However, determining this information would not have been possible with this method because the sensors can only store the data for 24 hours because of privacy matters. Therefore, other methods are needed to accomplish this.

In both datasets, I assume that I am only assessing with international visitors, using the argument that Icelandic residents are less than 400,000. Based on the findings from domestic surveys, Icelanders travel mostly during the summer, especially in July. Therefore, the error is most likely to be greater during the summer than the winter.

These research methods are a valuable addition to other methods used to analyse tourism mobility patterns. As all other methods, they have their limitations. I argue that data should be collected as automatically as possible, especially in rural areas, where the collection of data can be expensive. In this study, I tried to make the methods as automated as possible. Even so, I had to spend a significant time calibrating counters on site and subsequently comparing the equipment counts to my manually collected data. Therefore, I conclude that the methods presented in this research are an important addition to others, but not the ultimate solution. In future studies it would be interesting to use cameras for the calibration of the vehicle counters and then artificial intelligence to analyse the data.

For a more complete understanding of tourism mobility patterns in Iceland, future research should provide a factual understanding of the situation, by asking the visitors why they travelled as they did. Therefore, I suggest that new research should be implemented, using questionnaires and/or interviews in combination with the research methods developed and tested in this study, to deeply explore and examine several hypotheses that are derived from this current work.

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Paper 1

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A method to analyse seasonality in the distribution of tourists in Iceland

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A R T I C L E I N F O

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A B S T R A C T

Iceland has enjoyed increased popularity among tourists during the last few years. In 2010, 459 thousand visitors came to Iceland but in 2015 about 1,3 million visited the country. Before 2010 seasonality was high but has decreased since. This is reflected in the changing amount of overnight stays in the capital area. The same has not happened in other regions of the country where seasonality is still high. It seems that during the off-peak season the visitors are overnighting in the capital region and taking day tours to destinations in South and West Iceland. Overnight stay data does therefore not give complete picture of travel behaviour and how tourists distribute around the country. Therefore a new approach is needed.

The paper describes a method that analyses seasonality in the number of tourists at nature destinations in South and West Iceland. The data is obtained from vehicle counters. Seasonality at the destinations is then expressed numerically by computing the Gini coefficient. Finally the Gini coefficients are compared for the destinations, regional overnight stays and departures from Keflavík International Airport.The paper provides a methodological approach to analyse seasonality and the distribution of tourists in an efficient manner.

Management implications:

- The study provides important tools for analysing seasonality in the distribution of tourists on three levels: Nationally, regionally and at destination level. This is vital when planning tourism and gives a more complete picture of seasonality and the distribution of tourists than using only overnight stay data.
- Managing seasonality at a destination level requires having reliable data about the number of visitors. This can be obtained economically by counting vehicles arriving at the destination.
- For destination management it is important to know the number of tourists at all times during the year. It is important for deciding the amount of infrastructure and the staff required.
- Computing the Gini coefficient is important when comparing seasonality between destinations or regions as well as between years. Having a numerical measure of seasonality makes the comparison reliable and easy.

1. Introduction

Iceland is sometimes said to be at the edge of the world, being an island far north in the Atlantic. Even so the country has in the last few years enjoyed increased popularity among tourists. In 2010 the annual visitation to Iceland was 459 thousand. Until then Iceland was a typical summer nature destination where 50% of visitors came in the period from June to August. In 2015 the annual visitation had increased to 1,3 million and 40% of the visitors came from June to August. From 2010 to 2015 the number of tourists in the three-month summer period had increased from 230 thousand to 515 thousand. At the same time the number of off-peak tourists did increase considerably, from 229 thousand to 785 thousand (Icelandic Tourist Board, 2017). In comparison the population of Iceland is only 330 thousand (Statistics Iceland, 2016b).

This dramatic increase has made tourism very important for the Icelandic economy and it has become one of its three main pillars. Tourism is now more important than both the fishing industry and the aluminium industry, until now the main industries in Iceland. In 2015 the percentage of foreign exchange from tourism was around 30% but 22% from the fishing industry and 20% from the aluminium industry (Statistics Iceland, 2016c).

The increase in the number of tourists has created several challenges for the management of tourism in Iceland. There is a lack of staff in the tourism industry and many employees are now coming from abroad. The infrastructure was not prepared for the massive increase. That relates to infrastructure at the destinations as well as to public infrastructure as roads and health care. The transportation system in Iceland has been insufficiently funded since the economic crisis in 2008 and with increased tourism the road system is inadequate and is becoming

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dangerous in some areas.

A further problem is that the regional distribution of tourists is quite uneven. Some regions receive more tourists than they can comfortably handle, while other regions still experience high seasonality and few tourists. It seems that during off-peak the visitors are overnighting in the capital region and taking day tours to destinations in South and West Iceland (The capital city Reykjavík, 2011). Therefore, the revenues from tourism are mostly created in the capital area and the income from tourism does not contribute to funding infrastructure in all the regions where it is required. When solving these problems it is necessary to know the number of visitors and the destinations they visit. It is difficult to allocate resources to infrastructure without knowing the level of use.

The aim of this project is to develop a method that compares data about visits to nature tourist destinations with data about where tourists overnight. That makes it possible to evaluate the pressure of tourism on nature and local communities and compare where the income from tourism originates and where the cost occurs. The results are expected to be useful for the government when making a comprehensive management plan for the country and when distributing money to infrastructure.

This paper describes a part of the project, a method that analyses seasonality in tourist distribution in Iceland. It uses data about the number of visitors at tourist destinations obtained by counting vehicles arriving at the destinations. The data is analysed using the Gini coefficient and the actual number of visitors.

2. Tourism development in Iceland

2.1. The growth of Icelandic tourism

In the last four to five years tourism in Iceland has expanded greatly, on average 21% per year from 2010 to 2015. Fig. 1 compares the increase in tourist arrivals/departures internationally and in Iceland from 1995 to 2015. The growth internationally has been relatively stable, on the average 4% in the 20-year period. Until 2010 tourism in Iceland behaved similarly, the average increase was 6%. In 2011 there was a dramatic increase in Icelandic tourism that has continued since. Between 2011 and 2012 the growth was 19%, but between 2014 and 2015 the growth was 29% (Icelandic Tourist Board (2017); World Tourism Organization (UNWTO) (2015)).

The reason for this great increase is not known. There is probably not one single explanation but a variety of causes. Iceland was until 2008 considered to be an expensive destination. In 2008 there was a financial crisis in the world that affected Icelandic economy greatly. The value of the Icelandic currency dropped and it became less expensive to travel to Iceland. In 2011 the volcano Eyjafjallajökull erupted and grasped great attention all over the world. To minimize the effect of negative discussion about how safe it was to visit Iceland the marketing agency Promote Iceland started a campaign called Inspired by Iceland. In the years since the promotion campaigns have continued. The focus has evolved during the years and is now on reducing seasonality. Whether the reason for the increased tourism is one of the above mentioned or something else is not clear and will not be discussed in this paper.

This great increase was not expected and Iceland was, and still is, not prepared for it. The infrastructure both at destinations and generally in the country was unprepared. The destinations lacked facilities to service this number of guests. There were far too few accommodations as well as trails, parking places and toilet facilities. A further problem was a lack of staff to service the guests. Public services as health care and law enforcement were badly financed. The same applied to public infrastructure as roads. The problems are therefore varied, from narrow roads to how to distribute the income from tourism fairly to the municipalities that bear the burden of the tourist flow. Municipalities get most of their income from local taxes that are paid by local inhabitants and companies registered in the municipality. Many of the tourism companies are registered in the capital area where they pay their local taxes (The Icelandic Travel Industry Association, 2017). Consequently they do not leave much behind in the regions.

2.2. Seasonality in Icelandic tourism

Along with this great increase there has been a major change in when tourists arrive and visits outside the high season have increased considerably (Fig. 2).

It is desirable to be able to express the seasonality numerically. This is frequently done by calculating the Gini coefficient (further discussion on numerical indicators in Section 4.2). The Gini coefficient takes values from zero to one. The closer it is to zero the less seasonality and the closer it is to one the more seasonality. The Gini coefficient has been computed for the number of tourists departing from Keflavík International Airport for the years 2010–2015 (Table 1). In 2010 it was 0,31, but in 2015 it had decreased to 0,21. The reasons have not been fully analysed. Undoubtedly the before mentioned joint campaign by the government and the industry to minimize seasonality has had an effect.

Seasonality is problematic for the industry in many ways and less seasonality means more stable all year employment which is considered desirable. Although seasonality in the visits of foreign tourists has diminished this change is not experienced equally everywhere in the country. The regional variation is great as can be seen from analysis of overnight stay data (Table 2) (Statistics Iceland, 2015). In 2015 seasonality in the capital area (Gini = 0,16) was similar to the seasonality in tourist departures from Keflavík International Airport (Gini = 0,21). In regions outside the capital area seasonality was still considerable (Table 1). To ensure a more profitable and stable industry there is a wish to decrease seasonality everywhere and distribute visitors more evenly around the country. This is a common goal of the industry as well as both central and regional government. For this reliable and descriptive data is needed as is clearly stated in a recent policy paper by The Ministry of Industries and Innovation and The Icelandic Travel Industry Association (2015).

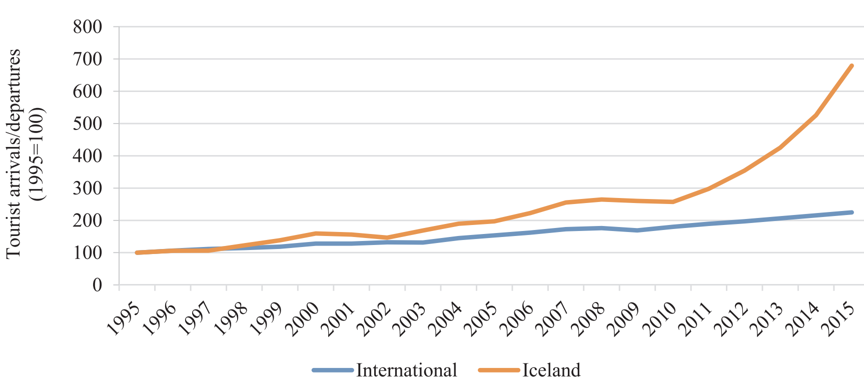

Fig. 1. Increase in tourist arrivals/departures internationally and in Iceland (Icelandic Tourist Board, 2017; World Tourism Organization UNWTO, 2015).

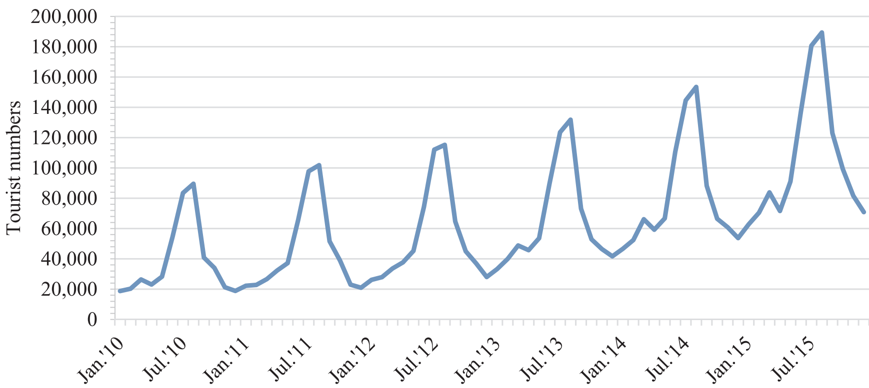

Fig. 2. Tourism seasonality 2010–2015, departures from Keflavík International Airport (The Icelandic Tourist Board, 2016).

Table 1
Gini coefficient for departures from Keflavík International Airport from 2010 to 2015 (The Icelandic Tourist Board, 2016).

Year	2010	2011	2012	2013	2014	2015
Gini coefficient	0,31	0,32	0,29	0,25	0,22	0,21

The overnight stay data show where the visitors overnight but not which destinations they visit. As mentioned before off-peak visitors tend to stay in the capital area and travel from there to other destinations as day visitors (The capital city Reykjavík, 2011). Therefore, overnight stay data does not give accurate results about which destinations and regions they visit. In this project the aim is to find a more suitable method.

3. Seasonality

3.1. Measuring seasonality

Tourism seasonality has been described as a temporal and spatial imbalance that can for example be seen in the tourist flow during the year (Connell, Page, & Meyer, 2015; Duro, 2016). The definition that seems to be the most acceptable one was made by Butler (1994), but he defined tourism seasonality as a temporal imbalance that can be expressed in terms of different indicators.

A wide range of measures has been used to analyse seasonal variation in tourism and an overview can be seen in Lundtorp (2001). The basic unit used to measure seasonality is the number of visitors. The analyses is usually made from overnight stay data or arrivals/departure data using days, weeks or months (Lundtorp, 2001). Such analysis has recently been made for the region of Andalusia in Spain by Martín Martín, De Dios Jiménez Aguilera, and Molina Moreno (2014). The authors used overnight stay data as well as arrivals of passengers on monthly basis. Cuccia and Rizzo (2011) used similar analysis when analysing seasonality in cultural destinations in Sicily.

According to Koenig-Lewis and Bischoff (2005) the most used tools to analyse tourist seasonality are: Coefficient of variation, seasonality ratio and the Gini coefficient. The Gini coefficient is defined and discussed in Section 4.2.

The coefficient of variation (*CV*) is the ratio of the standard deviation to the mean (the average). It is a measure of spread and describes the amount of variability relative to the mean. Because the coefficient of variation is unitless it can be used instead of the standard deviation to compare the spread of data sets that have different units or different means:

$$CV = \frac{s}{\bar{x}}$$

where s is the standard deviation and $\bar{x}$ is the mean value, of for example the monthly values. Lundtorp (2001) argues that even though *CV* is an easy measure it is difficult to describe an appropriate interpretation of the coefficient.

Seasonality ratio (*SR*) is found by dividing the highest value by the average value:

$$SR = \frac{x_{max}}{\bar{x}}$$

The ratio increases with the degree of seasonal variation. Its lower bound is one and its upper bound is equal to the number of periods compared, twelve, when monthly data are used (Lundtorp, 2001). If the same number of visitors came every month the ratio would be one.

The seasonality indicator is the inverse value of the seasonality ratio:

$$SI = \frac{1}{SR} = \frac{\bar{x}}{x_{max}}$$

If the same number of visitors came every month the ratio would be one. This definition is used in utility analysis.

Both the seasonality ratio and the seasonality indicator are sensitive to the highest value. The Gini coefficient is not as sensitive to the highest value as the seasonality indicator but it is more sensitive to variations outside the peak season. In this study the Gini coefficient will be used to analyse seasonality at destinations (see Section 4.2).

4. Methodology

4.1. Study areas

The aim of the paper is to describe a method to find how tourists distribute in time and space. For the analysis six destinations with different properties in South and West Iceland were selected: Þingvellir, Hraunfossar, Djúpalónssandur, Seltún, Sólheimajökull and Jökulsárlón (Fig. 3). They are all easily reached by day tours from the capital area. They are all lowland destinations that are accessible all year round and have different nature attractions. Therefore the target groups may differ that can cause different seasonality. The infrastructure and service at the destinations varies as well as their management. The destinations belong to four different regions according to the regional definition

Table 2
Gini coefficient for regional overnight stays in 2015 (Statistics Iceland, 2016a).

Regions	Capital area	South-west	South	West	North-east	North-west	East	West-fjords
Gini coefficient	0,16	0,33	0,46	0,52	0,57	0,62	0,60	0,67

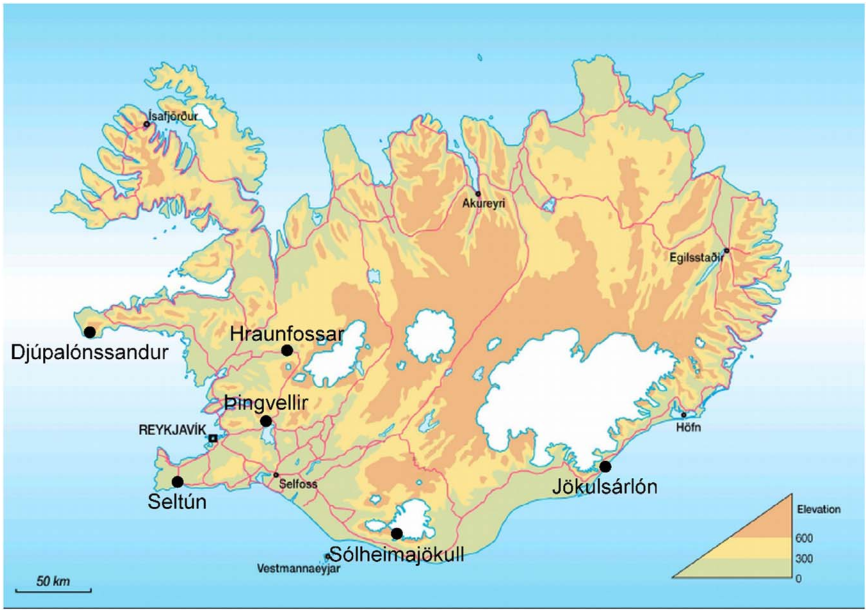

Fig. 3. The six destinations.

of Statistics Iceland (2015) that have different population characteristics.

Þingvellir is a national park and is on the World Heritage List of UNESCO because of its historical and cultural importance. The oldest parliament in the world was established there in 930 and was held there until 1798. This historical site has a very important place in the hearts of Icelanders, but it has important geological value as well. Here the Eurasian and the North-American tectonic plates are moving apart and the effects of the continental drift can clearly be seen. The drift has created impressive geological formations, faults and fissures that show the rifting of the earth's crust. Þingvellir is on a very popular day excursion from Reykjavík that includes Geysir, a hot spring area, and Gullfoss, a famous waterfall in Iceland.

Hraunfossar waterfall is an unusual natural phenomenon that has been protected since 1987. Clear spring water emerges from below the lava fields and runs in tiny waterfalls and rapids into the glacial river Hvítá. Hraunfossar is an hour´s and a half drive from Reykjavík.

Djúpalónssandur is on the Snæfellsnes peninsula inside Snæfellsjökull National Park, about three hour´s drive from Reykjavík. It is a sandy beach on a rocky coast and was previously a major fishing station near important fishing grounds.

Seltún in Krýsuvík is part of Reykjanes nature reserve, about half an hour´s drive from Reykjavík. It is a very colourful geothermal area on the Mid-Atlantic Ridge with many mud pots and fumaroles.

Sólheimajökull is an outlet glacier from Mýrdalsjökull, a neighbour glacier of Eyjafjallajökull that erupted in 2010. It is about two hour´s drive from Reykjavík. It has for many years been popular among Icelandic ice climbers. Recently a number of adventure firms run glacial walks there for tourists. The destination is on a popular day tour along the South coast.

Jökulsárlón is a picturesque glacial lagoon in front of Breiðamerkurjökull, one of the outlet glaciers of Vatnajökull icecap in South East Iceland. It developed when the glacier started receding from the coast. Jökulsárlón has been a setting for Hollywood adventure movies. It is a very popular destination and recently tourists have been making day tours to there from Reykjavík even in the middle of winter, although it is about five hours drive from Reykjavík.

4.2. Gini coefficient

The Gini coefficient is the most used tool to analyse seasonality (Duro, 2016). In this work it is used as a numerical measure of the degree of inequality in the number of visitations to a destination over the year. It is derived from the Lorenz curve that displays the cumulative frequency of the ranked observations starting with the lowest number. The formula can be expressed as follows as done in Lundtorp (2001):

$$G = \frac{2}{n} \sum_{i=1}^{n} (x_i - y_i)$$

where:

- n = the number of fractiles, months, weeks, days or other units
- x_i = the rank of fractiles, for example 1/12, 2/12… when using months, or when using weeks 1/52, 2/52…, or days 1/365, 2/365… etc. So $x_i = i/n$
- y_i = the cumulated fractiles in the Lorenz curve

The Gini coefficient is equal to the area between the Lorenz curve (area A) and the 45° line divided by the whole area below the line (area B) (Fig. 4):

$$\frac{A}{A + B}$$

To find the area between the Lorenz curve and the 45° line, area B needs to be found. The Gini coefficient can equally well be calculated from monthly, weekly or daily values. The values are first ordered by size from the lowest value to the highest value and then normalised by

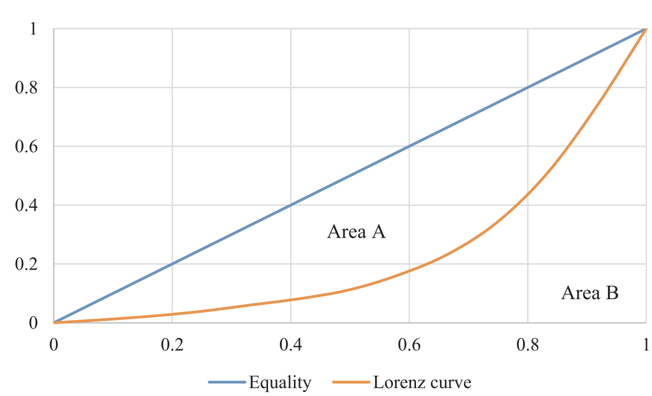

Fig. 4. The Lorenz curve for Hraunfossar.

the total number of visitors over the year (v_t).

$$\frac{v_1}{v_t}, \frac{v_2}{v_t} \ldots\ldots \frac{v_n}{v_t}$$

n equals to the number of fractiles, 12 when using months, 52 when using weeks and 365 when using days.

The sum of the normalised values should be one. The normalised values are then accumulated and the highest of the accumulative values should be one, the largest fractile.

The next step in finding the Gini coefficient is to find the area below the Lorenz curve (area *B*). That is done by finding the mean of two neighbouring values and multiplying the mean by the width. The x-axis is normalised to one and therefore the width of each bar is 1/n. When the n values are summed up we have area *B*. Area *A* is given by:

$$A = 0,5 - B$$

The Gini coefficient is finally found:

$$Gini\ coefficient = \frac{A}{0,5}$$

4.3. The true seasons of tourism

When discussing seasonality it is important to work with typical tourism seasons. As Iceland was until recently first and foremost a summer destination it was customary to speak of summer and winter tourism. Summer being June to August, or July and August. Now it is common to speak about the summer, the winter and the shoulder seasons (spring and autumn) without defining precisely the limits of the seasons. With the change to more whole year tourism this is not a sufficient definition of the seasons of tourism. When this project started it was considered necessary to define the seasons and their limits. In the absence of a definition of tourism seasons it was decided to use seasons computed from the number of visitors to Skaftafell, a destination in Vatnajökull National Park. Skaftafell is a popular lowland destination on the South Coast that is visited throughout the year. Before 2014 Skaftafell was the only destination in Iceland where data on the number of tourists had been collected for several years on a whole year basis (Þórhallsdóttir and Ólafsson, 2015). Skaftafell was considered to be a representative destination with regard to composition and travel behaviour. Skaftafell is not used in this analysis as neighbouring Jökulsárlón was considered more representative for tourism in that region and its properties more suitable for this analysis.

It is assumed that each season is uniform with regard to target groups and travel behaviour. In this work this is important with regard to the composition of vehicles and the average occupancy of vehicles.

Seven seasons were found by fitting a series of straight lines to the normalised curve of the number of people arriving in Skaftafell from week 44 in 2011 to week 7 in 2013 (Fig. 5). The data are normalised with respect to week 32, in the beginning of August 2012. The fit was done by minimizing the standard error for each line segment. The quality of the fit was reasonable, the standard error being 5% or less for each season. The highest standard error was in the high season, or 5%. The lowest standard error was for the winter period, 1% and 2% for late winter. The standard error was 4% for the other seasons. The intercepts of adjacent lines mark the boundaries of the seasons. Every season was given a descriptive name (Fig. 5).

This is the first attempt to define tourist seasons in Iceland. With increased tourism and an extension of the high season it might require a revision in the future.

5. Study findings

5.1. Finding the number of visitors from vehicle counters

In this paper counting vehicles arriving at destinations is used to compute the number of visitors to the destination. This method relies on the fact that most tourist destinations in Iceland have one access road. That makes it easy to count vehicles in an economical and reliable way. The number of visitors can then be found by finding the average occupancy of the vehicles arriving at the destination.

The study uses TRAFx vehicle counters produced in Canada. They use a magnetometer to detect the changes in the earth's magnetic field when a vehicle passes by. The counters need to be set up for each destination and calibrated by manual counting to eliminate possible sources of errors. Visitors arriving by other means than in motor vehicles are not detected by the counters, but their number is insignificant.

When using vehicle counters to find the number of visitors the following need to be found and analysed. First the ratio of vehicle types (busses and private cars). Then the average occupancy of private cars and busses. From the ratio of vehicle types and the average occupancy of each vehicle type the average occupancy of a vehicle is computed.

5.1.1. The ratio of busses and their average occupancy

The ratio of busses is generally different between destinations and seasons. Preferably data should have been sampled in every season. As this has to be done manually it is expensive and unfortunately there were not enough resources for that. The sampling was therefore not optimal. Samples were taken three times during the year. The ratios in the periods between had to be approximated from adjacent seasons.

At each destination the ratio of busses to the total number of vehicles was found in three periods from June 2014 to March 2015 by counting manually the number of busses that came to the destinations. This was done for a week at each destination, from early morning before the traffic started until the end of the traffic, usually from 9:00 to 19:00.

Table 3 shows the number of vehicles in each sample (*n*), the ratio of busses (*%*) and the average occupancy of busses (*Avr.*) during the sampled seasons. The ratio of busses in Þingvellir and Sólheimajökull varies between the sampled seasons as can be seen in Table 3. There the ratio seems higher during the winter season when the weather is unpredictable and when there are fewer rental cars on the road. The destinations Djúpalónssandur, Hraunfossar, Jökulsárlón and Seltún have similar ratio of busses in the three sampled seasons.

The average number of passengers per bus is usually different between destinations and seasons and has to be found for each destination and each season. The project reported here involved both counting visitors as well as a survey of visitors‘ attributes (Sæþórsdóttir, Guðmundsdóttir, & Stefánsson, 2015; Sæþórsdóttir, Þórhallsdóttir, & Ólafsson, 2014). The data collection was done in collaboration between the projects. Busses that came to the destinations while the staff was collecting questionnaires were counted and the number of passengers recorded. It is assumed that all the busses arrive at the time that the staff was working. The number of busses and the total number of passengers were then added up and the average number of persons per bus computed (Table 3). Not all seasons were sampled. Data was only collected three times over the year at each destination giving data for three seasons. For seasons not sampled an approximation of the average occupancy was made from the sampled seasons (Table 5).

5.1.2. Average occupancy of private cars

In this work the average occupancy of private cars is taken to be 2,6 persons per vehicle. The number was found by counting the occupants of 952 vehicles that arrived at Skaftafell in Vatnajökull National Park during the summers of 2009–2013 (Ólafsson & Þórhallsdóttir, 2015; Þórhallsdóttir & Ólafsson, 2015) (Table 4). The number agrees well with data collected by the Icelandic Road and Coastal Administration (IRCA) in three surveys they made in connection with major road works in different parts of Iceland (The Icelandic Road and Coastal Administration, 2008a, 2008b, 2012) (Table 4). As can be seen in Table 4 the numbers agree reasonably well during the summer when the traffic is dominated by tourists. The lower figures of 2,11 and 2,55

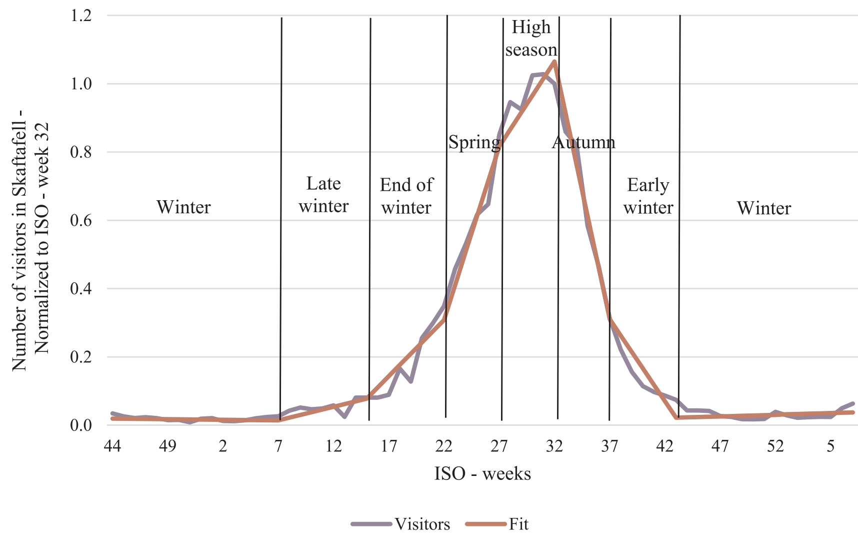

Fig. 5. Tourist seasons in Skaftafell from week 44 in 2011 to week 7 in 2013.

obtained by the IRCA in the winter is assumed to be caused by a higher ratio of local cars with fewer occupants, especially during weekdays.

5.1.3. *Computing the average occupancy of vehicles*

The average occupancy of vehicles *AOV* (private cars and busses) for each sampled season is found with the formula:

$$AOV = \{(AOPC*NPC) + (AOB*NB)\}/TNV$$

where *AOPC* is the average occupancy of private cars, *AOB* is the average occupancy of busses, *NPC* is the number of private cars, *NB* is the number busses and *TNV* is the total number of vehicles. The average occupancy (*AOV*) was calculated for each season that data were collected in. For the seasons not sampled the average occupancy of vehicles was found by linear interpolation from the two nearest sampled seasons.

In Table 5 the average occupancy of vehicles is presented. The numbers in bold are the averages for the sampled seasons. From Table 5 it can be seen that the average occupancy varies between destinations as well as between seasons.

When the average occupancy of vehicles has been found the number of visitors can be found for each destination.

5.2. *Seasonality at destinations*

Hours are the basic time unit when counting vehicles in this project. To filter out daily variations weeks are used as a time unit in the computations. As explained in Section 4.3 the average occupancy of vehicles is assumed to be the same within each season. When discussing tourist behaviour months are most frequently used. Monthly figures are easily computed from weekly values.

Table 6 shows the number of visitors in thousands at the destinations. Þingvellir is the most visited destination in every month. Jökulsárlón is the second most visited destination and then Sólheimajökull. The visitors there are much fewer than at Þingvellir and Jökulsárlón. In Seltún, Hraunfossar and Djúpalónssandur the visitation numbers are much lower than at the other three destinations.

When looking at the monthly numbers in Table 6, it is difficult to visualise the seasonal variation. The Gini coefficient assigns a numerical value to the seasonality which makes comparison between years and destinations possible. Table 7 shows the Gini coefficient for the six destinations calculated from monthly, weekly and daily values. The values are somewhat higher when calculated from shorter intervals but the difference is not large. In the project the daily values are used. It can be seen that seasonality is least at Sólheimajökull and Þingvellir, then comes Jökulsárlón. Seltún, Hraunfossar and Djúpalónssandur have higher seasonality (Table 7).

6. Discussion

The paper describes a method that analyses seasonality in the distribution of tourists. It uses vehicle counters to obtain the number of tourists. Iceland is a nature destination (Icelandic Tourist Board, 2014, 2016). Therefore nature destinations are used in this study for analysing where tourists go during their stay in Iceland.

Outside of high season many tourists stay in Reykjavík and take day excursions to destinations in neighbouring regions (The capital city Reykjavík, 2011). The overnight stay data give good information about where tourists stay during their journey to Iceland. However, in Iceland

Table 3
Number of vehicles, ratio of busses and the average occupancy of busses.

Destination	Djúpalónssandur			Þingvellir			Hraunfossar			Jökulsárlón			Seltún			Sólheimajökull		
Season	n	%	Avr.	n	%	Avr.	n	%	Avr.	n	%	Avr.	n	%	Avr.	n	%	Avr.
Late winter	93	6,5	22				331	5,1	14	1.484	2,8	17	457	5,5	26	345	18,8	25
End of winter																		
Spring	739	7,2	22	1.381	10,8	25										761	8,1	24
High season							1.566	5,8	23	4.522	3,1	21						
Autumn													1.015	6,9	15			
Early winter	148	2,7	29	1.441	12,1	23	330	5,8	20	1.423	2,6	18						
Winter				549	26,8	28							363	5,2	13	90	27,8	25

n = Total number of vehicles.
% = The ratio of busses the days that data were collected.
Avr. = Average number of passengers in busses the days that data were collected.

Table 4
Average occupancy of vehicles on Icelandic highways according to IRCA traffic surveys and as counted in Skaftafell.

	Traffic surveys – IRCA[a]								Skaftafell[b]	
	Average occupancy				Ratio between vehicles				Average occupancy	Ratio between vehicles
	Summer		Winter		Summer		Winter			
	Week days	Week-ends	Week days	Week-ends	Week days	Week-ends	Week days	Week-ends		
Private vehicles	2,64	2,65	2,11	2,55	98%	97%	99%	99%	2,60	88%
Busses	15,38	18,16	14,62	15,22	2%	3%	1%	1%	13,89	12%

[a] Icelandic Road and Coastal Administration (IRCA).
[b] Skaftafell is a natural area in Vatnajökull National Park.

Table 5
Average occupancy of vehicles.

	Djúpalónssandur	Þingvellir	Hraunfossar	Jökulsárlón	Seltún	Sólheimajökull
Late winter	**3,8**	5,9	**3,2**	**3,0**	**3,9**	**7,1**
End of winter	3,9	5,5	3,4	3,0	3,8	5,7
Spring	**4,0**	**5,0**	3,6	3,1	3,7	**4,3**
High season	3,7	5,5	**3,8**	**3,1**	3,6	5,0
Autumn	3,5	5,9	3,7	3,1	**3,5**	5,7
Early winter	**3,3**	**6,3**	**3,6**	**3,0**	3,3	6,4
Winter	3,6	**6,3**	3,4	3,0	**3,2**	**7,1**

Table 6
Number of visitors 2015.

	Þingvellir	Jökulsárlón	Sólheimajökull	Hraunfossar	Seltún	Djúpalónssandur
January	25	9	6	2	3	1
February	31	14	9	2	4	1
March	38	20	12	3	6	2
April	38	18	13	5	8	3
May	59	38	18	11	13	8
June	78	65	20	25	20	17
July	105	88	27	40	28	25
August	108	88	32	35	26	21
September	77	53	22	17	14	9
October	61	28	19	8	8	4
November	41	17	13	3	4	2
December	36	12	10	2	2	1
Whole year	697	450	201	153	136	94

Table 7
Gini coefficient for the destinations for 2015.

	Sólheimajökull	Þingvellir	Jökulsárlón	Seltún	Hraunfossar	Djúpalónssandur
Months	0,25	0,26	0,40	0,41	0,53	0,55
Weeks	0,28	0,27	0,41	0,42	0,54	0,56
Days	**0,29**	**0,29**	**0,41**	**0,45**	**0,55**	**0,57**

where visitors come mainly because of nature, it is important to have information about visitations at the destinations. For that other measurement approaches are needed. The method described here aims at fulfilling that gap.

The results are promising, but the method can be improved further by improving the sampling technique when finding the average number of occupants in vehicles. For that it is important to know the ratio between busses and private cars in every season at each destination. At each destination the sampling was done continuously for a week three times during the year. A better sample would have been obtained by distributing the data collection over the year. A week of bad weather could for example have influenced the sampling as well as special events.

The ratio of busses varied between destinations and sometimes within a destination. As sampling was not done for all seasons it was necessary to estimate intermediate values. In this project the ratio of busses was found manually. That is both time consuming and expensive. Collecting data automatically and continuously would improve the sampling and the accuracy of the results. That is being tested using radar with promising results.

When the Gini coefficient for departures from Keflavík International Airport is compared with the regional data on overnight stays, it can be seen that the seasonality in the capital region and departures is similar. In regions adjoining the capital region seasonality is higher. That indicates that off-peak tourists tend to stay in the capital area.

The Gini coefficient for the destinations does not always agree with the Gini coefficient for the overnight stays for the same region. Sólheimajökull and Þingvellir are in the South region. The South region has a higher Gini coefficient than both destinations. Jökulsárlón is a part of the South coast travel region but belongs to the East region. The East region has a higher Gini coefficient than Jökulsárlón that has a similar Gini coefficient as the South region. Seltún is a part of the Southwest region. The Gini coefficient for the Southwest is lower than for Seltún. As Seltún is an interesting geological site in a comfortable travel distance from the capital area this is rather surprising. The two destinations in the West region have similar Gini coefficient as the region.

This project is the first attempt to use vehicle counters at destinations to analyse seasonality in the distribution of tourists. Both the Gini coefficient and the actual number of tourists at the destinations are presented in this paper. The Gini coefficient is a good measure when comparing seasonality between destinations. The actual numbers are also required for a complete picture as the Gini coefficient does not give any indication about the number of tourists. In this study two of the destinations, Sólheimajökull and Þingvellir, have the same Gini coefficient, but the number of tourists are very different, as well as the characteristics of tourism. Therefore the actual numbers are important.

Analysing the distribution of tourists at destinations is valuable for a deeper understanding of seasonality in tourism. It also gives planners and managers of tourist destinations data that is valuable when planning service and infrastructure. In Iceland it is important to know how seasonality varies in different regions of the country. The method presented here provides a tool for the analyses that is required.

7. Conclusion

In this paper we have presented a method for analysing seasonality in the distribution of tourists, using data on seasonality at destinations. Analysing seasonality from destinations is an important tool when managing tourism in nature destinations and planning infrastructure and staff deployment. It is as well a tool for finding the distribution of tourists around the country. It is an important addition to more traditional methods like using overnight stay data. The data could be improved by better sampling.

The method is expected to be useful for the government when making a comprehensive management plan for the country, and when distributing money to improve infrastructure.

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Paper 2

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A methodology of estimating visitor numbers at an Icelandic destination using a vehicle counter and a radar

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A R T I C L E I N F O

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Destination management
Vehicle counters
Radar
Calibration

A B S T R A C T

Knowing the number of visitors to a destination is a basic requirement for the management of visitor services, experiences and impacts. This paper is a part of a long-term study that uses vehicle counters to compute visitor numbers at several Icelandic nature-based tourist destinations. All counters need to be calibrated for errors in the counting. Furthermore, when data on vehicle numbers are used to compute visitor numbers it is important to collect additional data. The counters cannot distinguish between direction, nor the size of the vehicle. Therefore, it is important to collect additional data on the ratio between private cars and buses, as buses carry far more people than private cars. Both the calibration of the counters and the length estimates have traditionally been done manually, which is time consuming and expensive. This paper describes an automatic method, using a microwave radar, to calibrate the counters and measure the length of the vehicles at the same time, making it easy to find the ratio between private cars and buses. As far as the authors know, a microwave radar has not been used for this purpose before. The reliability of the radar to calibrate the vehicle counters and measure the length of the vehicles was computed. The findings indicate that using radar to calibrate the counters is more reliable and economical than the traditional manual calibration.

Management implications: For the management of destinations, it is important to have reliable information on vehicle numbers, the ratio between vehicle types (private cars and buses), as well as visitor numbers. The study provides an important and novel method for calibrating vehicle counters automatically for errors. It is important to provide reliable vehicle numbers in cost-effective way. Automatic data collection makes it possible to collect data 24 h a day and during different seasons. This is the first attempt to use a radar to calibrate vehicle counters and analyse the reliability of the radar's length measurement.

1. Introduction

International tourist arrivals to Iceland expanded greatly in the wake of the global financial crisis in 2008 (Jóhannesson & Huijbens, 2010), on average 21% per year from 2010 to 2015, and reached 2,3 million in 2018. This growth then slowed down, and between 2018 and 2019 tourist arrivals decreased (The Icelandic Tourist Board, 2020b). The rapid increase posed serious challenges. The sub-arctic flora is especially vulnerable to environmental degradation due to overcrowding and trampling, meaning that a relatively low number of visitors may induce high impact (Jóhannesson, Huijbens, & Sharpley, 2010; Sæþórsdóttir, 2014; Ólafsdóttir & Runnström, 2013). Low population density, lack of material infrastructure, such as paved roads, together with long distances and stark seasonality present challenges to effective management. Therefore, reliable data is important for the management of visitor flows and planning in these areas.

Iceland has been a typical summer destination with high seasonality. In 2010 there were 459 thousand annual visitors and 50% of them came from June to August. In 2015, there were 1,3 million visitors and 40% of them came from June to August. In 2019, there were almost 2 million annual visitors and 34% of them came from June to August (The Icelandic Tourist Board, 2020b). Seasonality in tourist arrivals to Iceland has therefore decreased as the traditional low season has been experiencing proportionally higher increase in tourist arrivals.

There is still a difference in regional distribution in the summer and winter season. During the winter months, unstable weather conditions make travelling between regions in Iceland difficult (Arnason & Welling, 2019). Tourism is then much more concentrated in and around the capital area. The majority of visitors overnight in the capital area and take day tours to destinations in South and West Iceland (Thórhallsdóttir

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& Ólafsson, 2017), leaving the revenues from tourism mostly in the capital area. One reason for the uneven distribution is the location of Keflavík International Airport in South-West Iceland, used by 98,9% of visitors, easily reached from the capital area even during the winter (The Icelandic Tourist Board, 2020a).

This paper is a part of a long-term study that has used data from vehicle counters to estimate the number of visitors at important tourist destinations in Iceland. There are more than 100 counters operated, mainly in the South and in the Central Highlands. The visitor numbers are used to analyse the distribution of tourists in time and space in Iceland for management purposes but are as well useful to analyse and manage crowding. To estimate the number of visitors to a destination using vehicle counters it is necessary to know the number of vehicles, the ratio between vehicle types and the average occupancy of each vehicle type, as buses carry far more people than private cars.

Several methodological and practical challenges need to be considered to get reliable numbers from vehicle counters. Each counter needs to be carefully set up and calibrated for counting errors. Traditionally the calibration has been done manually, which means that someone has to register each vehicle and the vehicle type for several hours and compare this data to the counter data (Ross, 2005). Manual calibration is expensive and time-consuming and is usually only possible during staff working hours. In this paper a new economical method of calibrating the counters by radar is described. Apart from counting passing vehicles the radar can measure their length. This can be used to find the ratio between private cars and buses. The accuracy of the radar's length measurement was tested and analysed with the purpose of finding the ratio between vehicle types at destinations.

The aim of the paper is to:

- Compare the two calibration methods, manual calibration and the radar calibration.
- Analyse the reliability of the radar to calibrate vehicle counters.
- Analyse the reliability of measuring the length of vehicles by radar.
- Analyse the ratio between vehicle types.
- Estimate the number of visitors.

The study area in this paper is Landmannalaugar, a popular destination in the southern part of the Icelandic Central Highlands (Fig. 1). Landmannalaugar is a part of the Fjallabak Nature Reserve. The area is known for its colourful mountains and a geothermal nature pool. There are many hiking trails in the area, and one of the most popular hiking trails in Iceland, Laugavegur, starts in Landmannalaugar (Ólafsson, 2014).

Landmannalaugar is the most visited destination in the Highlands, attracting more than 86 thousand visitors from June to September 2019. Even though there is much to see and do in Landmannalaugar many visitors only stay there for a short time. Results from longitudinal research in Landmannalaugar show that the number of day trips has increased from 263 in 2009 to 471 in 2019. During the same time the number of overnight visitors has decreased from 825 in 2009 to 775 in 2019 (Sæþórsdóttir & Hall, 2020). Many seem to visit only the local nature pool or take short hikes near the visitor centre (Ólafsson, Þórhallsdóttir, & Rögnvaldsdóttir, 2017).

The paper is divided into six sections, including the Introduction. Section 2, Literature review, describes what other researchers have done to compute reliable visitor numbers. In section 3, Methods, the methodology of the paper is described in five sub-sections. In section 4 the methodology is tested, and computations are made in seven sub-sections. In section 5 the results are analysed and discussed. The paper finishes on section 6, Conclusion.

2. Counter calibration and the number of visitors

Knowing the number of visitors to a destination is a basic requirement for the management of visitor services, experiences and impacts (Cessford & Burns, 2008). The number of visitors to a destination can be determined by several methods. Each method has its pros and cons, and the best method needs to be found for each destination, a method that is practical and within the financial limits of the project.

Cessford and Burns (2008) have divided the counting methods into four categories:

- Direct observation, e.g. fixed observers and video recordings.

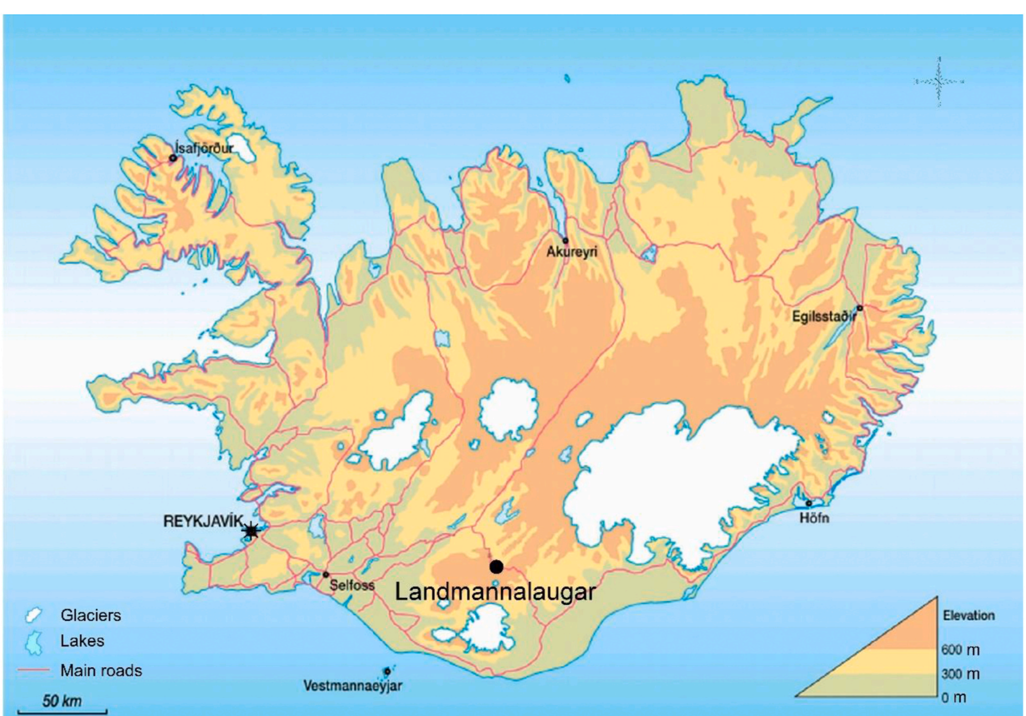

Fig. 1. Landmannalaugar, location.

- On-site counters, e.g. vehicle and trail counters.
- Visit registration, e.g. voluntary registration.
- Inferred counts are not useful in visitor counting but give additional information on the visitor and its behaviour (Cessford & Burns, 2008).

Automated vehicle counters have for a long time been used to find out the number of visitors to a destination. They simplify the work of counting but need to be carefully set up and calibrated for errors in the counting (Watson, Cole, Turner, & Reynolds, 2000). In recent years researchers have been testing new ways and methods to compute visitor numbers. Among methods that have been tested are on-line data sources, social media (Sessions, Wood, Rabotyagov, & Fisher, 2016) and the cell phone (Qin et al., 2019). The results are promising and a valuable addition to traditional counting. In transport analytics the new data should be validated against an existing data set that has been confirmed for accuracy, for example data from automated vehicle counters (Streetlight, 2019).

Destinations with only one entrance and exit are best suited for counting vehicles as no estimates need to be made on how people drive to the destination (Cessford & Burns, 2008). When vehicle counters are used to determine the number of visitors at a destination the ratio between vehicle types and the average occupancy needs to be found and computed (Ross, 2005). This was done for some destinations in Iceland during the years 2014 and 2015 at the same time as other research on tourism carrying capacity (Sæþórsdóttir, Guðmundsdóttir, & Stefánsson, 2015) and by the rangers in Skaftafell in Vatnajökull National Park in 2013. In Skaftafell, the rangers counted occupants from private cars and buses, but in the research in 2014 and 2015 the occupants in buses were counted (Thórhallsdóttir & Ólafsson, 2017). The Icelandic Road and Coastal Administration (IRCA) have as well collected data on occupants in private cars and buses (The Icelandic Road and Coastal Administration, 2012).

Leggett (2015) gives a comprehensive description of setting up and selecting a good location for the counter. When the right location and suitable settings have been chosen for the counter, it should be calibrated for counting errors. Ross (2005) and Leggett (2015) give a detailed description of the traditional methodology of counter calibration in their reports. On their web page, TRAFx Research Ltd. gives information on how to calibrate a counter. They point out that calibrating a counter takes time, effort and diligence. Calibration should only be performed if specific management questions require such accurate data (TRAFx Research Ltd., 2017).

Traditionally the calibration is done manually. A staff member counts every vehicle that passes the counter for a given time and compares the results to the counter readings. From that a calibration coefficient is computed. The calibration coefficient (CC) is found by dividing the manual counting (MC) with the readings from the vehicle counter (VC) and is used for correcting the data (Ross, 2005).

$$CC = MC/VC$$

For how long should the calibration be done and when? This is a trade-off between the accuracy required and the staff time available for the fieldwork. Visitor behaviour and vehicle types can vary between days of the week and between seasons. The optimal number of days for the fieldwork is not easy to determine, and different organizations use their own approach. A straightforward method would be to sample data for one weekday and one weekend day for each counter (Ross, 2005). When preparing for major road construction in Iceland, such as tunnels, the Icelandic Road and Coastal Administration samples data for three days, two weekdays, Thursday and Friday and one day during the weekend, Saturday (The Icelandic Road and Coastal Administration, 2008a, 2008b, 2012).

The calibration defines the calibration coefficient of the counter. Preferably the calibration should be repeated periodically because these multipliers can change over time when the nature of the traffic changes. The time between the calibration periods is not easy to determine; however, accuracy can be greatly increased by repeating calibration regularly (Ross, 2005). Where very accurate data is required, significant staff time will be spent on calibration work. Where a high level of accuracy is not practical or necessary, calibration can be made less frequently (Ross, 2005). Calibrating the vehicle counters manually has its pros and cons. It is very expensive and time-consuming for the staff, but it is valuable when monitoring visitor behaviour. During the manual calibration the staff can, for example, record the vehicle types. It is important to know the ratio between the vehicle types because usually the aim is to compute the number of visitors at a destination. There may be seasonality in this ratio as was found in research conducted in Iceland in 2014 and 2015 (Ólafsson & Þórhallsdóttir, 2015).

Time lapse-cameras have been found useful for calibrating counters. In addition to finding the counters calibration coefficient, they can be used to distinguish between vehicle types. This is important when the aim is to know visitor numbers. The cameras can capture a great deal of information, but they do not count automatically. The researcher still needs to analyse the images manually but can reduce the work by using partly automated software to deduce the number of frames to review. That saves time and produces more accurate counts than a fully manual system, because the human eye can easily miss a count when doing it for a long time (Fisher et al., 2018). This might change as computer vision gets more and more capable of detecting and quantifying objects and people (Staab, Taubenböck, & Job, 2018).

Apart from estimating the number of visitors to tourist destinations, vehicle classification data is important in numerous transportation applications, for example, road surveillance, traffic control, traffic safety, road planning and pavement maintenance. Knowing the vehicle types is important in roadway design and in the development of automatic toll charging systems. There are various vehicle classification methods that use different data collection methods, for example, axle-based methods, vehicle sound-based methods, vehicle-length-based methods, video-based methods and radar-based methods. Each method has its strengths and weaknesses regarding costs, accuracy, performance and ease of use (Wu et al., 2019). A microwave radar system is more accurate in speed measurement than the other methods and can additionally be used to compute the length of the vehicle (Fang, Meng, Zhang, & Wang, 2007).

There are several kinds of radars and they are used for different measurements, for example, weather radars and navigation radars. Many transportation studies have used a radar to collect data for vehicle detection and classification. A microwave radar is most frequently used. Microwave radars mostly work on the X-band, around 10 GHz, or K-band, around 24 GHz, with fixed antennae. They can be divided into pulse Doppler radars, unmodulated continuous wave radars and frequency-modulated continuous wave radars (Fang et al., 2007).

When vehicle counters are used to compute visitor numbers, it is important to know the average occupancy of vehicles. This number cannot be found automatically but needs to be manually collected. To get reliable data on the average occupancy of vehicles, a proper sampling has to be used. Proper sampling would, for example, be to sample at different times of the day and repeat the sampling at different seasons (Thórhallsdóttir & Ólafsson, 2017).

3. Methods

3.1. The counters

The project this paper is based on uses vehicle counters that sense vehicles by detecting changes in the magnetic field when a vehicle passes. They are placed beside the road in a location where the speed of vehicles is steady, the road is narrow and preferably where two vehicles do not easily meet. The counters are made by TRAFx Research Ltd. in Canada (www.trafx.net). They are small, 10 × 15 × 15 cm, and come in a small waterproof box that in the field is placed inside another waterproof box. The counters run on batteries that last for around six months.

When a counter is set up at a new destination it is calibrated manually for several hours to select its best settings. There are two important settings. The rate must be set to slow or fast, depending on the speed of the vehicles at the destination. The delay factor is the minimum time between two vehicles. The delay factor is important: If it is too long, the counter might miss vehicles driving close to each other, but if it is too short, it might count a long slow-moving vehicle as two vehicles. This study finds the optimum settings by placing several test counters with different settings beside the counter. The test counters record every vehicle passing by. At the end of the calibration period their count is compared with the manual counting and the settings that agree best with the manual count are selected for the counter. Finally, the counter is set to record the number of vehicles passing each hour.

The counters record every vehicle that passes, independent of direction and vehicle size. In Iceland, the majority of the most visited tourist destinations have only one entry/exit road. To know the number of vehicles arriving at a destination the count from the counter is divided by two. For obtaining the number of visitors from the number of vehicles it is important to be able to detect the size of the vehicles, as private cars and buses carry different number of occupants. For that, other methods are needed. In this study, length measurements by radar are tested for that purpose.

3.2. The radar

The study has tested a radar, both for calibrating the counters and finding the length of vehicles. The radar is manufactured by Sierzega in Austria (https://www.sierzega.com/en-us/). To measure correctly, the radar must be properly set up with the right angle to the traffic to be recorded. Many radars are difficult to set up and need to be placed high, at least 3 m above the road level. Therefore, they are not very easy for one person to set up and align. The Sierzega radar is easy to use and can be moved from one place to another by one person. It is set up beside the road and detects traffic in both directions. It must be placed 1 m above the road level, and the angle should be 30° to the driving direction. The radar runs on batteries that last up to 16 days but can also be run from solar cells. The radar records date, time, vehicle length, speed, direction and the time between vehicles.

To get accurate length measurements, the mounting and alignment of the radar are important. It needs to be set up carefully and checked manually for several hours to ensure that it is counting properly. It should be mounted so that it points towards the approaching direction. As said before, its optimum mounting height is 1 m above the road level and its angle should be 30° to the driving direction. After it has been set up the radar needs to be tested and the traffic monitored manually for some time to see if the radar is counting and measuring properly. If not, the angle should be changed a few degrees at the time until the radar is recording properly. This testing is done by comparing the length of vehicles of known lengths to the radar's length measurement.

Sierzega recommends to use only the length measurements of vehicles in the approaching direction (Sierzega Elektronik GmbH, 2015). Even so, it was decided to record the length of four common vehicle types in both directions. The directions were analysed separately, and a separate correction factor was found for each direction. In that way the radar's length measurements are calibrated in both directions, and more accurate data is collected. This length calibration was then checked by comparing the calibrated results with the actual length of other vehicle types that were recorded at the same time.

3.3. The setup in Landmannalaugar

The radar and the counter were both set up beside the access road to Landmannalaugar. They detected the same vehicles and were manually tested for 13 h on July 1st and July 2nd, 2016, during normal working hours. During that time, 488 vehicles were manually counted, 489 were recorded by the counter and 482 by the radar. The instruments were then left for 18 days to record all passing vehicles, generating a second data set. During this period, the vehicle counter recorded 8.814 vehicles. These were recorded as vehicles passing each hour. The radar recorded 9.714 items. The radar records day and time for each item.

3.4. The analysis of the datasets

Two overlapping datasets were obtained. The first dataset was collected during working hours on the 1st and 2nd July 2016. Every vehicle that passed the instruments was manually recorded as well as its length and travel direction. The manual data was compared to the counter data, comparing the number of vehicles. It was also compared to the radar data, comparing the number of vehicles, as well as their length and travel direction. The data was used both to calibrate the counter and fine adjust the length measurements of the radar as described in section 3.2. The second dataset was collected automatically with both the radar and the counter from July 1st to July 18th, 2016. Both recorded 24 h a day. The vehicle counter detects vehicles. The radar counts vehicles and measures their length at the same time. The vehicle counts of the counter and the radar were then compared to find out how well the radar could be used to calibrate counters. The length measurements were used to find the ratio of private cars and buses visiting Landmannalaugar.

When analysing the data, it was obvious that there were some outlaws in the radar's dataset. This could be seen from the length measurement, the recorded speed and the time gap between the items. The road to Landmannalaugar is a highland gravel road and only used by 4 × 4 vehicles and small- and medium-sized buses. There are hardly any motorcycles in Landmannalaugar. Apart from recording vehicles the radar records every large item that passes – be it a bicycle, horse, or a hiker. There are the occasional bicycle riders and hikers on this road, and it happens that a pack of horses passes by. To clean up the radar's dataset it was decided that the shortest vehicle that visited the destination was Suzuki Jimny, a very small and short 4 × 4 vehicle, 3,5 m long. It was also decided that the longest bus to Landmannalaugar was 12,0 m long. As the radar's manufacturer, Sierzega, claims ± 20% accuracy in its length measurements, it was decided that valid detections of vehicles from the radar would be vehicles of length down to 20% lower than the length of the shortest vehicle and 20% longer than the length of the longest bus. Valid records from the radar are therefore taken to be where the length measurements are from 2,8 m to 14,4 m. Records outside this range were considered to be outlaws and were removed from the radar's dataset, which then numbered 8.574 items.

3.5. The ratio between vehicle types and the average occupancy

When the final aim of counting vehicles is to know the number of visitors to a destination it is important to know the ratio between vehicle types. This study has divided vehicles into private cars and buses. This study only counts vehicles at tourist destinations where other kinds of vehicles are rare. The ratio between vehicle types can be different between destinations and seasons (Thórhallsdóttir & Ólafsson, 2017).

When data has been collected manually, private cars have been defined as vehicles with nine passengers or less and buses with more than nine passengers. Using the radar, private cars were defined as vehicles from 2,8 m up to 6,9 m. Buses were defined from 7,0 m up to 14,4 m.

The study uses 2,6 as an average occupancy of private cars independent of season and destination. The number was found by counting occupants of 952 vehicles that arrived at Skaftafell in Vatnajökull National Park during the summers 2009–2013. The number agrees well with data collected by the Icelandic Road and Coastal Administration in preparation for major road works in different parts of Iceland (The Icelandic Road and Coastal Administration, 2012; Thórhallsdóttir & Ólafsson, 2017). The average occupancy of buses is different between destinations and seasons (Thórhallsdóttir & Ólafsson, 2017). The average occupancy rate has unfortunately not been collected for Landmannalaugar. Therefore, an estimate needs to be made for the average occupancy of buses in Landmannalaugar. The estimate is made from other destinations where the average occupancy of buses has been collected (Thórhallsdóttir & Ólafsson, 2017).

4. Study findings

4.1. Manual calibration of the radar

On Fig. 2, the data from the manual counting and the radar counting, corrected for outlaws as described in section 3.4, are compared. Both directions of travel were used. For the radar, each hour's count was summed up for all length measurements and compared with the manual count. This manual calibration was done for 13 h. It should be noted that two points have the same value, therefore, only 12 points are visible on Fig. 2. On Fig. 2, the manual counting data is on the Y-axis and the radar counting on the X-axis. Linear comparison gives Y = 1,0131 and R^2 = 0, 9979. The radar seems to be overcounting (Y) by around 1%.

4.2. Manual calibration of the counter

On Fig. 3, the manually collected data is compared to the Landmannalaugar counter data. The manual counting is on the Y-axis and the radar counting on the X-axis. The comparison gives Y = 1,0027 and R^2 = 0,9936 (Fig. 3), indicating that the time constant of the counter was suitable.

In addition to the Landmannalaugar counter four test counters with different time constants were used to find the most suitable time constant. The settings of the Landmannalaugar counter gave the best results.

4.3. Calibrating the radar length measurements

As one of the aims of using the radar was to find the ratio between vehicle types, the accuracy of its vehicle length measurement has to be determined (see section 3.4). The radar detects vehicles travelling in both directions and distinguishes between them, here between those travelling to Landmannalaugar and those travelling from Landmannalaugar. As mentioned in section 3.2 the manufacturer Sierzega recommends only to use the approaching direction. In this case both directions were calibrated for errors and therefore used in the analysis. Four common vehicle types of known lengths were used for the analysis. The vehicles were Dacia Duster, 4,2 m, Kia Sportage, 4,4 m and Toyota Land Cruiser and Nissan Patrol, both 4,9 m. The two shorter groups contain popular rental cars and the 4,9 m group includes popular 4 × 4 vehicles, much used both among foreign tourists and Icelanders. As expected the accuracy of the length measurements of the radar was found to be different between directions (Fig. 4 and Fig. 5).

When the two radar datasets, of incoming and departing vehicles, were analysed and compared to the manually collected data, the data towards Landmannalaugar (N = 71) gave Y = 1,0126 (Fig. 4) and the data from Landmannalaugar (N = 68) gave Y = 0,8659 (Fig. 5).

These two different constants are used to calibrate the radar's length measurements by multiplying the measured value with the appropriate constant. The constant Y = 1,0126 is used to correct the dataset to Landmannalaugar and the constant Y = 0,8659 is used to correct the data from Landmannalaugar.

4.4. Testing the calibration of radar's length measurements

To test the accuracy of the calibration of the radar's length measurements the first dataset that was collected on July 1st and 2nd, 2016 was used. Apart from the four vehicle types used for correcting the radar's length measurements, the length of 13 other vehicle types was manually recorded and used to test the calibration (Table 1). The number of vehicles in each group varies from 5 to 41. The shortest vehicle was 3,5 m and the longest 4,9 m. From the calibrated measured length of each vehicle, the average measured length of each vehicle type was computed (see section 4.1) as well as the root mean square for each vehicle group. The distribution of the values in each group is highest for the shortest vehicle, 0,69 m, but least for the longest vehicle, 0,26 m. The 95% confidence range was computed for the 13 groups used in the test. The real length of the vehicles is well within the 95% range for all the 13 vehicle types. The results are shown in Table 1 and Fig. 6.

The accuracy of the radar's length measurements is found by comparing the average length of each of the 13 groups, as calculated in Table 1, with the actual length of the vehicles (Fig. 6). The slope of the graph of average length measurements against the actual length of the vehicles was computed. The computations were done using weighted least squares straight line fitting. The root mean square deviation for each vehicle type was used as weight (Fig. 6). The average length of the vehicles, as well as the upper and lower limit of the length using the 95% range, can be seen on Fig. 6. It also shows the trendline using the method mentioned above. The slope of the line is Y = 1,0000 the computed error in the slope is err = 0,0006 or 0,06% (Fig. 6).

4.5. Radar calibration of the counter

The radar was used to calibrate the counter over a longer period than is possible with manual calibration, from July 1st to 18th, 2016. As the counter counts the number of vehicles per hour, the records from the radar were summed in the same way.

All corrected records from the radar (see section 4.1) of vehicles of lengths from 2,8 m to 14,4 m were used for the calibration of the counter (see section 3.4). Measurements shorter than 2,8 m and longer than 14,4

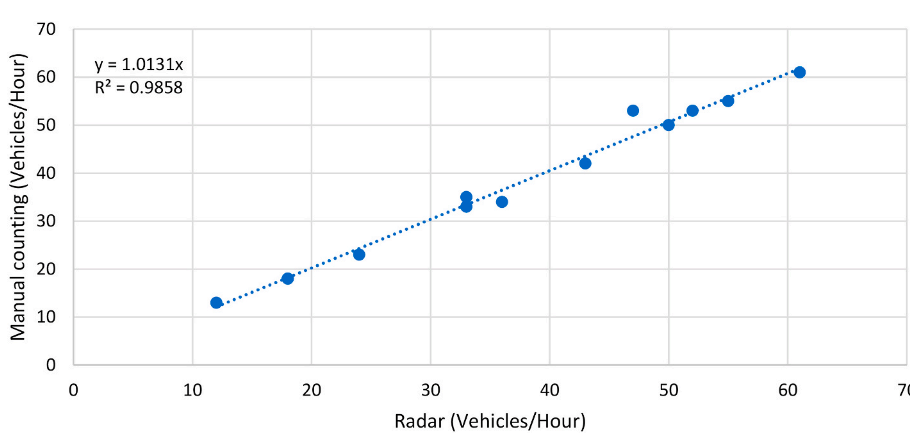

Fig. 2. The manual counting compared to the radar counting, July 1st and 2nd, 2016.

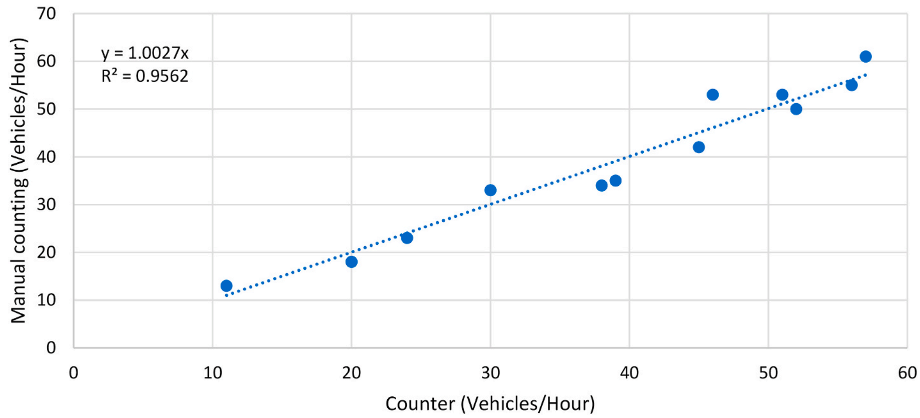

Fig. 3. Landmannalaugar, the counter calibrated manually, July 1st and 2nd, 2016.

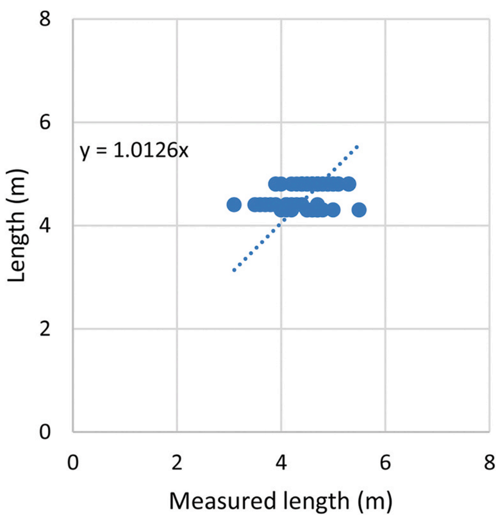

Fig. 4. To Landmannalaugar. N = 71.

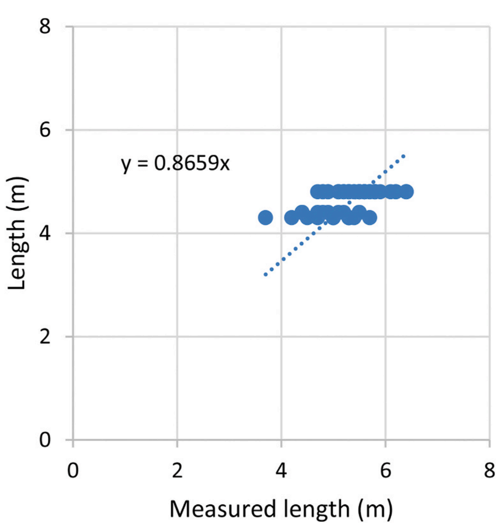

Fig. 5. From Landmannalaugar. N = 68.

m were considered outlaws. One further outlaw was found and deleted. During that hour, the average speed was very low and the gap between detected items shorter than to be expected between vehicles. The counter registered a much lower value than the radar. Therefore, this outlaw could have been a pack of horses as there are quite many horse trips to Landmannalaugar. The radar counting is on the Y-axis and the vehicle counter is on the X-axis. The comparison gives Y = 0,9975 and R^2 = 0,9838 (Fig. 7).

4.6. Ratio of vehicle types in landmannalaugar

During the 13-h calibration time (July 1st to 2nd 2016) in Landmannalaugar there were 488 vehicles manually recorded, 451 private cars (92%) and 37 buses (8%). The radar collected data as well during this time and was then left to collect data in Landmannalaugar until the end of July 18th, 2016. The data the radar collected was corrected using the criteria explained in former sections. During these 18 days the radar recorded 8.973 vehicles, 8.155 private cars (91%) and 818 buses (9%) (Table 2).

4.7. Computing the number of visitors

When the ratio of buses has been found the number of visitors can be computed if the average occupancy of buses is known or can be estimated. This study counts vehicles to Landmannalaugar every summer from the opening of the road in the spring until it is closed in the autumn. The data that was collected in July 2016 to calibrate the counter and to find the ratio between vehicle types is used compute visitor numbers for all other years. As an example, the number of visitors to Landmannalaugar was computed in July 2016 and July 2019. The following assumptions were made: The ratio of buses was assumed to be 9% and private cars 91% (Table 2). The average occupancy of vehicles is then computed for three bus occupancies; 15, 18 and 21 passengers per bus (Table 3). The average occupancy of private cars is assumed to be 2,6.

These occupancies were selected as estimates using data from previous studies (section 3.5). In July 2016 there were 8.921 vehicles counted towards Landmannalaugar giving 35.600 ± 2.700 visitors. In July 2019 there were 7.999 vehicles counted towards Landmannalaugar or 31.900 ± 2.400 visitors.

5. Discussion

This paper has compared two methods to calibrate vehicle counters, a traditional manual calibration (section 4.2) and a new method using a radar (section 4.5). The reliability of the two methods was then analysed (sections 4.1 and 4.4). The radar's length measurement, which is used to find the ratio between vehicle types was analysed in section 4.3. In section 4.6 the ratio of vehicle types in Landmannalaugar is analysed using the radar, and in section 4.7 the average occupancy estimate is put forward. The study has used vehicle counters for more than a decade to estimate the number of visitors to tourist destinations. The radar is

Table 1
Vehicle types used for testing the accuracy of the correction of the radar's length measurements.

N	Vehicle Type	Length (m)	Average Measured Length (m)	Root Mean Square Deviation	95% Range	Upper Limit	Lower Limit
41	Suzuki Jimny	3,50	3,97	0,69	1,73	5,71	2,24
32	Suzuki Grand Vitara	4,20	4,27	0,37	0,92	5,20	3,35
5	Nissan Quasqai	4,20	4,40	0,25	0,62	5,02	3,77
6	Nissan Terrano	4,35	4,47	0,18	0,44	4,91	4,03
23	Kia Sportage	4,40	4,11	0,40	1,00	5,10	3,11
6	Land Rover Discovery	4,50	4,45	0,42	1,06	5,51	3,39
5	Land Rover	4,50	5,04	0,37	0,93	5,97	4,10
15	Mitsubishi Pajero	4,50	4,67	0,32	0,81	5,47	3,86
6	Subaru Forrester	4,60	3,84	0,53	1,34	5,18	2,50
6	Land Rover Defender	4,60	5,00	0,36	0,91	5,90	4,09
12	Toyota RAV4	4,60	4,21	0,27	0,68	4,89	3,53
9	Huyndai Santa Fe	4,70	4,37	0,29	0,71	5,08	3,65
11	Toyota Hilux	4,90	5,01	0,26	0,66	5,66	4,35
177							

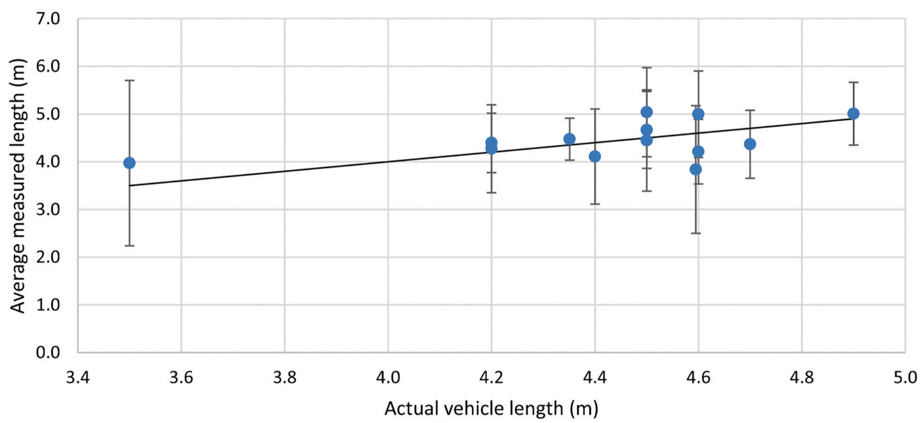

Fig. 6. The accuracy of the radar's length measurement.

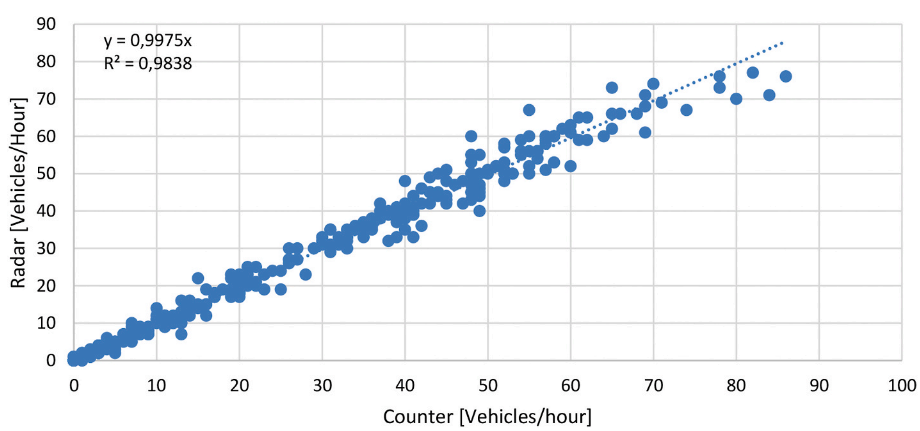

Fig. 7. Landmannalaugar, the counter calibrated with a radar from July 1st to 18th, 2016.

promising to improve the computations and the quality of the work. It collects additional data in a more reliable and economic way than is possible with manual methods. When a counter and a radar are set up at a new destination, both should be tested for several hours with manual counting to ensure proper setup. When the radar has been set up it can be used both to calibrate the counter and to find the ratio of vehicle types by measuring their length. This way, the calibration of the counter is made over a much longer period than is practical with manual calibration and both during quiet and busy times.

Data was collected manually for 13 h on July 1st and 2nd, 2016. The data was used to calibrate the counter manually and fine adjust the radar's length measurement. The radar was then used for 18 days, from July 1st to 18th, 2016, to collect data to calibrate the vehicle counter and to evaluate the radar's length measurement.

The accuracy of the radar's length measurement was evaluated by measuring the length of four vehicle types (see section 4.3) on July 1st and 2nd, 2016. Data from both directions of travel was recorded and compared to manually collected data. As expected, the accuracy of the radar's length measurement was found to be different between travel directions. The direction towards Landmannalaugar was more accurate than the direction from Landmannalaugar (see section 4.1, Figs. 4 and 5). Correction constants were then found for each direction and used to correct the radar's length measurements for both directions of travel. The constant Y = 1,0126 was used to correct the data towards

Table 2
Number of vehicles to Landmannalaugar and the ratio between private cars and buses.

Weekday	Date	Time	Number of vehicles	Number of private cars	Ratio of private cars	Number of buses	Ratio of buses
Friday	July 1, 2016	16:00–23:59	130	117	90%	13	10%
Saturday	July 2, 2016	24 h	476	441	93%	35	7%
Sunday	July 3, 2016	24 h	428	391	91%	37	9%
Monday	July 4, 2016	24 h	447	409	91%	38	9%
Tuesday	July 5, 2016	24 h	506	472	93%	34	7%
Wednesday	July 6, 2016	24 h	532	480	90%	52	10%
Thursday	July 7, 2016	24 h	490	443	90%	47	10%
Friday	July 8, 2016	24 h	416	368	88%	48	12%
Saturday	July 9, 2016	24 h	524	471	90%	53	10%
Sunday	July 10, 2016	24 h	426	382	90%	44	10%
Monday	July 11, 2016	24 h	468	421	90%	47	10%
Tuesday	July 12, 2016	24 h	561	520	93%	41	7%
Wednesday	July 13, 2016	24 h	692	623	90%	69	10%
Thursday	July 14, 2016	24 h	635	577	91%	58	9%
Friday	July 15, 2016	24 h	412	383	93%	29	7%
Saturday	July 16, 2016	24 h	597	538	90%	59	10%
Sunday	July 17, 2016	24 h	546	498	91%	48	9%
Monday	July 18, 2016	24 h	687	621	90%	66	10%
Total			8.973	8.155	91%	818	9%

Table 3
Estimated average occupancy of vehicles in Landmannalaugar.

Average occupancy of buses	15	18	21
Average occupancy of vehicles	3,72	3,99	4,26

Landmannalaugar, and the constant Y = 0,8659 was used to correct the data from Landmannalaugar. This corrects both inaccuracy in the physical setup of the radar and the difference between the measurements in the two traffic directions. Using this method the setup of the radar is quicker and it is possible to measure the length of vehicles travelling in both directions (see section 4.1). This is important, as the counter counts vehicles travelling in both directions and does not distinguish between directions.

The accuracy and quality of the correction of the radar's length measurements was tested using 13 vehicle types, different from the ones used for the original calibration. The average measured length of each vehicle type was computed from the corrected measured length from the radar (section 4.3). The average length and the root mean square deviation were found for each vehicle group. The distribution of the values in each group is highest for the shortest group, 0,69 m, but least for the longest vehicles, 0,26 m (see Table 1 in section 4.4). Why the shortest vehicle, Suzuki Jimny, measured the worst is hard to say. It might have something to do with how it is built, high, square and short. The distribution in the data for that group was much higher than for the other vehicle groups.

As one aim of the study is to use the length measurements to find the ratio between vehicle types, it is vital that the radar measures the length of vehicles accurately. The radar measurement is promising. For all the 13 vehicle types the real length of the vehicles is well within the 95% range.

As explained in section 4.6, the ratio of buses was 8%, using the manual counting (13 h) but 9% from the radar counting (18 days). Using 9% and average occupancy 2,6 of private cars and three different average occupancy values of buses, 15, 18 and 21 gave three different average occupancy values of vehicles. These numbers were then used to compute visitor numbers in July 2016 and July 2019 in Landmannalaugar (section 4.7). At destinations where very accurate visitor numbers are important, the average occupancy should be collected.

The results are very encouraging. There are destinations where the amount of traffic is so high that it is almost impossible to calibrate the counters manually. There the radar is very helpful. It is also useful at destinations where the traffic is very light. At such places, a researcher using a manual calibration needs to stay for hours to get a few calibration points. That is both time consuming and expensive. Additionally, the radar's length measurement is very useful when determining the ratio between vehicle types. This is important when estimating the number of visitors to a destination from the vehicle counters. For that the average occupancy estimation of each vehicle type needs to be manually collected (Thórhallsdóttir & Ólafsson, 2017).

6. Conclusion

In this paper two methods to calibrate vehicle counters were compared, the traditional manual calibration and a new automatic calibration, using radar. The radar can at the same time be used to measure the length of passing vehicles, which can be used to group the traffic into groups of vehicles with different occupancy, for example cars and buses. That is useful when estimating the number of visitors to a destination.

This is the first attempt to use a radar to calibrate vehicle counters and analyse the reliability of the radar's length measurement. The radar can collect data 24 h a day and during different seasons. Both when traffic is at its minimum and maximum. The radar collects more information than is possible to collect manually, and the errors can be statistically analysed.

Reliable data is the key to successful planning and policy making for nature-based tourism in vulnerable areas like in Iceland. The use of automatic calibration of vehicle counters is advantageous for developing more robust destination management.

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Paper 3

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Mobility Patterns and Sustainable Tourism:

Planning and Managing Tourism in Iceland

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Abstract

Tourism in Iceland has experienced significant changes in the past decade. Visitor numbers increased from 459,000 in 2010 to 2.3 million in 2018. However, there was a 14% decrease in visitor numbers between 2018 and 2019, and in 2020, the visitor numbers collapsed because of the COVID-19 pandemic. The effect of the pandemic started to decrease in spring 2022 as visitors returned.

The great increase from 2010 to 2018 prompted Icelandic authorities to focus on sustainable tourism management in their policymaking. The focus has been on distributing the flow of visitors and associated revenues more evenly across regions, while protecting the main tourist attraction: nature, as well as nature-based destinations. Knowledge of mobility patterns at different scales is crucial for the sustainable development and management of tourism. This study analyses mobility patterns in Iceland through examining visitor numbers at 18 nature-based destinations scattered around the country. The mobility patterns are then related to the sustainable tourism objectives of the Icelandic tourism authorities.

The results indicate that the south and southwest region of Iceland is more visited and exhibits less seasonality than other regions of the country. Seasonality has decreased in all regions but not to the same extent as in the south and southwest, the area that includes both the main gateway, Keflavík International Airport, and the capital city of Reykjavík, which often serves as a basecamp for natural attractions. When planning for and managing sustainable tourism in Iceland, it is crucial to know the number of visitors at nature-based destinations, as these numbers are key for analysing mobility patterns.

Keywords: Sustainable Tourism, Mobility, Time and Space, Seasonality, Iceland, Arctic

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Introduction

In recent years, there has been a growing interest in nature and the Arctic as a tourist destination (Maher et al., 2022). This trend is evident in Iceland, where the number of visitors increased significantly from 2010 to 2018 (The Icelandic Tourist Board, 2024). In 2020 there was a collapse in visitor numbers because of the COVID-19 pandemic, but since then, the tourism industry has rapidly recovered and is now, in terms of number of international visitors, back on a similar track (Figure 1). The Arctic regions, including Iceland, have low population densities spread across vast areas. Many similarities exist in tourism across the Arctic region, such as high seasonality and uneven regional distribution of visitors, which results in uneven distribution of revenues (Huijbens, 2022; Maher et al., 2022; Rantala et al., 2019).

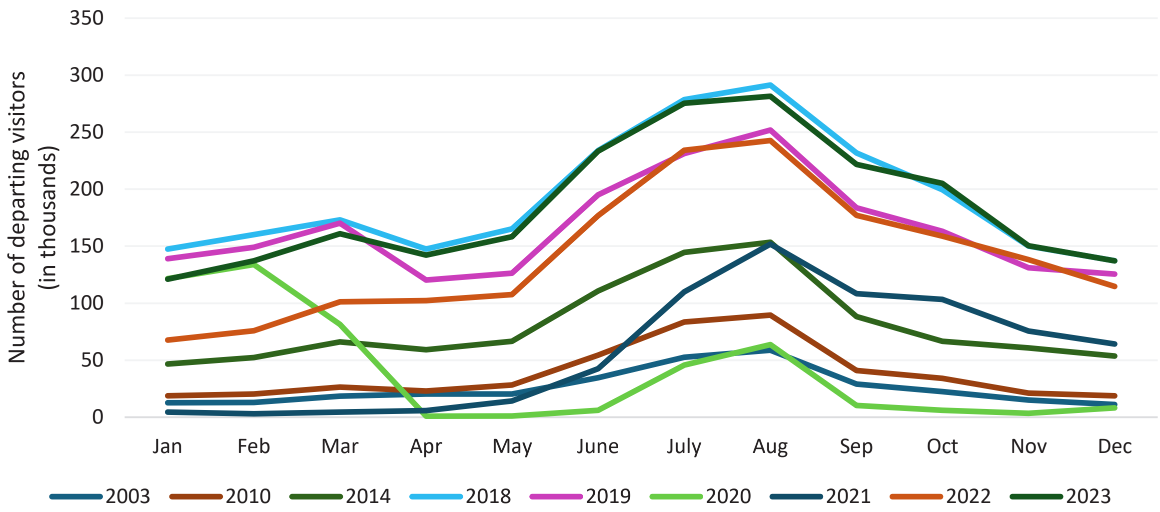

Figure 1. *Number of visitors departing Keflavík International Airport (The Icelandic Tourist Board, 2024).*

In Iceland, tourism authorities have promoted sustainable tourism planning and management for decades (Jóhannesson et al., 2010), which has been loosely translated into an aim to reduce regional seasonality and distribute the flow of international visitors from the main gateway to Iceland, Keflavík International Airport, which is used by 99% of all international visitors (The Icelandic Tourist Board, 2024). The focus has also been on protecting nature, distributing revenues from tourism more evenly around the country, and protecting both locals and tourists from the negative experiences of tourism. Concrete examples of efforts working towards more sustainable tourism are the establishment of the Tourist Site Protection Fund, the National Plan on the Development of Tourist Sites (Lög um landsáætlun um uppbyggingu innviða til verndar náttúru og menningarsögulegum minjum nr. 20/2016), and the development of Vakinn in 2012, which is a quality and environmental assurance initiative (The Icelandic Tourist Board, n.d.-a). The Tourist Site Protection Fund was established to promote the development, maintenance, and protection of tourist attractions and tourist routes in Iceland and to alleviate pressure on highly visited sites by increasing the number of tourist sites (The Icelandic Tourist Board, n.d.-c). The aim of the National Plan is to formulate and coordinate a strategy for the development, operation, and maintenance of infrastructure in the interest of nature conservation and for the protection of cultural and historical monuments due to pressure caused by tourism and outdoor recreation (Lög um landsáætlun um uppbyggingu innviða til verndar náttúru og menningarsögulegum minjum nr. 20/2016).

Despite these efforts, Isavia, the airport operator in Iceland, has emphasised the expansion of Keflavík International Airport, and plans to triple the airport's size before 2040. Less focus has been placed on strengthening other regional airports, such as Egilsstaðir in the east and Akureyri in the north (Huijbens & Jóhannesson, 2020). Keflavík International Airport is in southwest Iceland, less than an hour´s drive from the capital area of Reykjavík and its surrounding municipalities (Figure 2). Reykjavík is the single most visited destination in Iceland and serves as an independent destination and basecamp, as well as, increasingly, a gateway to natural attractions in neighbouring rural areas (Huijbens & Jóhannesson, 2020; Jóhannesson & Welling, 2020).

Growth in urban-based tourism in the Arctic is not unique to Iceland. Urban areas are often perceived as offering better value for money, more choices, and higher standards than rural areas (Carson et al., 2020). This preference for urban areas is prevalent in various Arctic countries and other regions characterised by long distances between service hubs and natural attractions (Müller et al., 2020). Consequently, distance decay is a prominent factor. The more distant and therefore less accessible destinations inevitably lose out, unless they manage to provide the scale, quality, and uniqueness required to overcome distance (Prideaux, 2002). This is seen in, for instance, Sweden, where the highly populated south is much more visited than the less populated north. Both areas have similar attractions, landscapes, and natural resources, but the south, with the capital city Stockholm in the southeast, Gothenburg in the southwest, and Malmö in the south, is much more accessible for international travellers than the north (Lundmark & Carson, 2020). An important consequence of an urban centre serving as a basecamp is that excursions rarely go beyond an easy commuting distance from the city (Carson et al., 2020). Day tours from urban areas reduce the time and money spent in rural areas and affect the potential for sustainable development of tourism in rural regions.

In this paper, sustainable tourism management is analysed through regional seasonality in time and space. The following research questions are addressed:

- To what extent have tourism authorities in Iceland succeeded in reducing regional seasonality?
- How can the analysis of visitor numbers at nature-based destinations contribute to planning and management for sustainable tourism?

To answer these research questions, data on the number of visitors at 18 nature-based destinations and at Keflavík International Airport are used. The visitor numbers are derived from counters at the nature-based destinations but also from a border survey. The mobility pattern is analysed by comparing the sites and the ratio between the sites and Keflavík International Airport but also from vehicle counters on the highway along the southern coast. Seasonality at the nature-based destinations and the airport is analysed using the Gini coefficient and the ratio of visitors between seasons.

Managing for Sustainable Tourist Mobility

Understanding the mobility patterns of tourists, including their destinations in time and space, is essential for sustainable tourism management (Lew & McKercher, 2006). The mobility pattern of tourists relates to how services, such as transportation and diverse infrastructure, are planned and managed (De Cantis et al., 2015). As international travel increases, it is becoming increasingly important to plan and manage tourism to protect all those affected by it, as well as the destinations themselves (Beeco et al., 2013). Therefore, it is important to understand the mobility patterns of tourists and their travel behaviour at all levels, making several factors key in tourism mobility planning and management: transportation in its broadest sense (Scuttari et al., 2013), accessibility to a destination (McKercher & Lew, 2003), and distance (McKercher, 2018). The distance a tourist can travel from their starting point is highly influenced by their available travel time (Hall, 2005). Transportation technologies have developed greatly, becoming more efficient and economical, and with increased leisure time, travel has become a part of many people's routine (Hall, 2012).

As tourism is based on travel, the transportation system plays a vital role in connecting tourist destinations. If the transportation system is inconvenient, tourists will seek alternative routes and destinations (Qian Pei et al., 2022). While spatial mobility has expanded with advancements in transportation technology, time for travelling remains limited for most people (Hall, 2005). Private and rental cars have the advantage over public transportation in that they allow tourists to travel faster, and therefore further, in less time (Dickinson et al., 2013). Individual vehicles also give tourists more flexibility and autonomy to change course during their travels. The internet, social media, and mobile phones have also greatly influenced tourism mobility (Gössling & Stavrinidi, 2015; Urry & Larsen, 2011) and where visitors go during their travels (Cohen et al., 2014).

The concept of distance decay, proposed in the 1960s (McKercher & Lew, 2003), explains why in the case of tourism, visitation to a site decreases as distance increases (Hooper, 2015). According to the distance decay theory, the further a destination is away from a starting point, the fewer visitors it will attract (Yee & Ismail, 2020). Additionally, if many destinations provide similar experiences, the one closest to the starting point is likely to be the most visited (Hooper, 2015). However, other factors also influence the distance travelled from a starting point. The effect of distance may vary, and its effect in one area may be different from its effect in another area. The effect of distance therefore also depends on the attraction and the accessibility of the destination (McKercher & Lew, 2003).

Hägerstrand's (1970) concept of time geography, introduced in the 1960s (Kang, 2016), is a conceptual framework that describes a behaviour in time and space (Grinberger et al., 2014). Time geography focuses on the movement and interaction of individuals in time and space. While initially focused on daily routines like commuting and local activities, time geography has become one of the most influential theoretical frameworks for describing tourism mobility. Like daily travel, tourism travel is constrained by time and space resources. Time geography enables observation of the complex connection between space, time, and mobility, a relationship that can be challenging to study. A study of German car tourists in Sweden revealed that those who stayed for shorter periods tended to travel more each day than those who stayed longer. The visitors also stayed the longest in the region farthest away from their home (Zillinger, 2007). Zillinger (2007) found that the tourists followed a discernible mobility rhythm that was not only shaped by the tourist attractions but also by the proximity of these attractions to other sites, the distance from the tourists' residences, and the duration of the tourists' stays in Sweden.

Sustainable tourism management aims to minimise the negative impacts that can occur from tourism, e.g., on nature, local communities and on the tourists themselves. Many countries have developed strategies based on the three pillars of sustainability (economic, sociocultural, and environmental), seeking to balance the impacts of tourism on these three aspects (Mihalic et al., 2021). However, scholars have criticised the use of the sustainability concept as it inadequately addresses practical needs and challenges (Sharpley, 2020). Nevertheless, the discussions on sustainability have drawn attention to the need for future-oriented tourism planning (Mihalic, 2016; Mihalic et al., 2021).

Tourism in Iceland

Tourism Development

Before 2010, international tourism in Iceland was highly seasonal and hardly existed outside the three summer months of June, July, and August (The Icelandic Tourist Board, 2024). Increased interest in the Arctic as a tourist destination (Maher et al., 2022) has benefitted Iceland as a sub-Arctic country located between North America and Europe with good air connectivity (IATA, n.d.). Visitor numbers increased significantly, from 459,000 visitors in 2010 to 2.3 million in 2018 (Figure 1). In 2019, there were nearly 2 million annual visitors, with 42% of these arriving during the summer (The Icelandic Tourist Board, 2024). The reason for the decrease in visitor numbers between 2018 and 2019 is not fully known. Then at the beginning of the COVID-19 pandemic in April 2020, the number of visitors collapsed. Even so, there were 482,000 total visitors to Iceland in 2020, which is not far off the number of visitors in 2010. In June 2021, visitor numbers began to recover, and the second half of 2022 was similar to the second half of 2019. The years 2018 and 2023 were also similar in visitor numbers (Figure 1) (The Icelandic Tourist Board, 2024).

The tourism sector has become the most important industry in Iceland's economy in terms of foreign currency income (Statistics Iceland, 2022). However, Iceland was not prepared for the rapid growth in tourism, which created numerous challenges for tourism management at all levels. In 2019, international visitors stayed in Iceland for an average of 7.9 nights during the summer (May to October) and 5.2 nights during the winter (January to April and November and December in the same calendar year). The tourists drove more during the summer than during the winter, and the use of rental cars has also been increasing; many foreign visitors now use a rental car to explore Iceland. In 2009, 37% of visitors used a rental car, but in 2019, 60% of visitors chose a rental car for their travel within Iceland (Guðmundsson, 2020).

The Research Area

The most visited nature-based destinations in Iceland were selected for analysis in this study to reflect the distribution of the tourist flow in Iceland. The sites are located in the so-called Golden Circle, along the Ring Road around Iceland, on Reykjanes Peninsula in the southwest, on Snæfellsnes Peninsula in the west, and in the Westfjords in the northwest (Figure 2). All of these sites have protected area status in one form or another (Reykjanes Geopark, n.d.; The Environment Agency of Iceland, n.d.; Vatnajökull National Park, n.d.).

The Golden Circle travel route is a day tour from the capital area along the lowlands east of Reykjavík. The main attraction on this route is the Geysir area with its hot springs, including the erupting hot spring Strokkur. Nearby is Gullfoss, a large and spectacular waterfall located on the river Hvítá. The third main attraction on the Golden Circle route is the UNESCO World Heritage site Þingvellir National Park. This historic site is where the Icelandic parliament was held from the tenth to the eighteenth century. Þingvellir National Park is situated in a rift valley created by the separation of two tectonic plates (Figure 2). The traffic on the popular Golden Circle route is comprised primarily of tourists (Guðmundsson, 2020).

In general, traffic on the Ring Road, in the lowlands, and around 100 km west and east of the capital area, is mostly local traffic. This is not the case further east from Seljalandsfoss to Jökulsárlón, where there are few inhabitants, and the traffic is mostly international visitors (Guðmundsson, 2020). East of Reykjavík on the Ring Road along the South Coast is Katla UNESCO Global Geopark, which was established in 2010 and includes a sequence of nature-based destinations (Figure 2). The westernmost site is the Seljalandsfoss waterfall, about 125 km east of Reykjavík. Further east, 55 km from Seljalandsfoss, is the bird cliff Dyrhólaey. The bird cliff is a rock arch that has been protected by the Icelandic government since 1978 to preserve its natural beauty and birdlife and to provide visitor enjoyment. East of Dyrhólaey is Reynisfjara, a black sand beach with unique rock formations, and the rock formations Reynisdrangar, which rise from the sea. Further east is the village Vík. Skaftafell is 150 km east of Reynisfjara and was established as a national park in 1967; since 2008, it has been a part of Vatnajökull National Park, and a UNESCO World Heritage Site. Skaftafell is considered, by many, to be a natural pearl with an exceptionally scenic landscape and many hiking trails. Further east along the South Coast, 378 km from Reykjavík, is the glacial lagoon Jökulsárlón, which has been a part of Vatnajökull National Park since 2017. East of Jökulsárlón is the town Höfn. The easternmost site on the South Coast used for this analysis is Vestrahorn, which is around 470 km from Reykjavík (Figure 2). The South Coast is important for the tourism industry in Iceland, as it offers a chain of different nature-based destinations that are popular among tourists (Ólafsson & Thórhallsdóttir, 2018; Thórhallsdóttir, 2023). The Icelandic Road and Coastal Administration (IRCA) has placed vehicle counters along the South Coast that can be used to analyse the traffic in the region. Figure 2 demonstrates the locations of IRCA's counters, from Hvammur in the west to Smyrlabjörg in the east.

Going further anticlockwise along the Ring Road, there are few important destinations until reaching the geothermal area Námaskarð in the northeast. Near Námaskarð are two large waterfalls, Dettifoss, which is in the canyon of the glacial river Jökulsá á Fjöllum, and Goðafoss, which is in the river Skjálfandafljót. Ásbyrgi is a unique natural formation shaped like a horseshoe; it has many hiking trails. Dettifoss and Ásbyrgi are within Vatnajökull National Park. In the northwest, Hvítserkur is a basalt rock stack that rises from the sea and is home to numerous seabirds and seals (Figure 2).

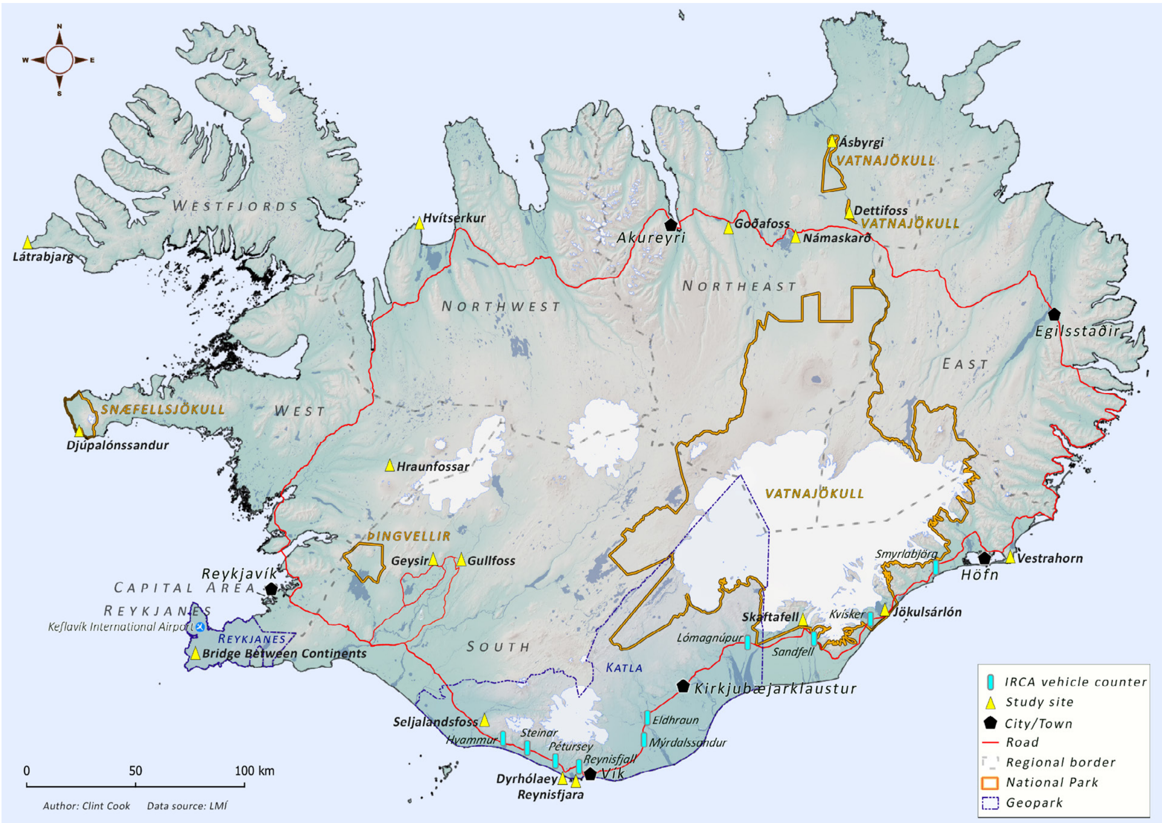

Figure 2 *Map of Iceland with the locations of the 18 nature-based destinations and IRCA's vehicle counters.*

In northwest Iceland are the Westfjords, which contain the bird cliff Látrabjarg, the largest of its kind in both Iceland and Europe. North of the capital area is Borgarfjörður, where the main attraction is Hraunfossar, a series of waterfalls formed by rivulets streaming out of the Hallmundarhraun lava field. West of Borgarfjörður is Snæfellsnes Peninsula, with which has interesting geological formations. The main attraction is Djúpalónssandur, a black sand beach located in Snæfellsjökull National Park. On Reykjanes Peninsula is Reykjanes Geopark, which has been a UNESCO Global Geopark since 2015. In Reykjanes Geopark is a small footbridge over a large fissure, called the Bridge Between Continents. It provides clear evidence of the presence of diverging tectonic plates (Figure 2).

Methods

Number of Visitors Departing Keflavík International Airport

To determine the number of visitors to Iceland, the number of visitors departing from Keflavík International Airport (Figure 2) is used in this analysis. The Icelandic airport service Isavia manually counts departing passengers as they enter airport security. All passengers who pass the security check are included in these numbers. They also include a small number who are not considered tourists, such as connecting passengers, those who did not spend any time in Iceland, and foreign citizens living temporarily in Iceland. The remaining majority, ranging from 86.3% to 92.7%, are considered tourists visiting Iceland for personal or commercial purposes (The Icelandic Tourist Board, n.d.-b). No correction is made for this inclusion in this paper, as the numbers are relatively small and can change over time.

Number of Visitors at Nature-Based Destinations

To analyse the mobility in time and space of international visitors in Iceland, data on the number of visitors at 18 nature-based destinations is used (Figure 2). This data derived from two datasets: vehicle counters at the access roads to the nature-based destinations and a border survey, *Dear Visitor*, conducted at Keflavík International Airport. The data for Geysir and Gullfoss in the south and Goðafoss in the north are derived from the border survey. The number of visitors at these three sites is computed from the replies to the survey and the number of departing visitors at Keflavík International Airport. One of the survey questions is to mark on a map which sites were visited during the travel in Iceland.

The data for the other 15 sites is derived from vehicle counters located at their access roads. They are managed by the first and second author of this paper. In Iceland, most tourist sites have only one access road. Every vehicle that passes a counter on the access road is counted and recorded, independent of the direction of travel and vehicle size. To determine the number of vehicles arriving at a site the count from the counters is divided by two. To obtain the number of visitors from the number of vehicles it is important to be able to detect the size of the vehicles as private cars and buses carry different numbers of occupants. Vehicle size measurement has been done both manually (Thórhallsdóttir & Ólafsson, 2017) and automatically using radar (Thórhallsdóttir et al., 2021). Average occupancy has been estimated from various data (Thórhallsdóttir & Ólafsson, 2015). The number of visitors at a site is computed from the formula:

*Number of visitors = Number of vehicles*The average occupancy of vehicles*

Table 1 indicates when the counting at the 18 nature-based destinations started at all sites and ended at Geysir, Goðafoss, Gullfoss, Hvítserkur, Námaskarð, Reynisfjara, and Seljalandsfoss. Sometimes the counting is interrupted by road construction or there is a malfunction in the equipment. This explains the empty cells in the sub-sections of the Results section.

Table 1. *Years when counting began and ended.*

	Started	Ended
Ásbyrgi	2010	-
Bridge Between Continents	2017	-
Dettifoss	2010	-
Djúpalónssandur	2014	-
Dyrhólaey	2017	-
Geysir	1996	2020
Goðafoss	1996	2020
Gullfoss	1996	2020
Hraunfossar	2014	-
Hvítserkur	2015	2021
Jökulsárlón	2012	-
Látrabjarg	2017	-
Námaskarð	2015	2020
Reynisfjara	2017	2022
Seljalandsfoss	2017	2020
Skaftafell	2009	-
Vestrahorn	2011	-
Þingvellir	2014	-

The Ratio between the Sites and Keflavík International Airport

To evaluate the importance of each site, the number of tourists counted at Keflavik International Airport is compared to the number counted at each site. This calculation is performed for the entire year, as well as separately for the summer and winter seasons:

Percentage of tourists that visit site =
Number of tourists at Site/Number of visitors departing from Keflavík International Airport

In the analysis of the vehicle counter data, it is assumed that everyone arriving at the sites is a foreign visitor, as the number of Icelandic visitors is negligible. This assumption is justified by the fact that the total population of Iceland in 2019 was around 360,000 (Statistics Iceland, 2020), while the number of international visitors to Iceland was almost two million (The Icelandic Tourist Board, 2024). This assumption does not apply to Gullfoss, Geysir, and Goðafoss as the *Dear Visitor* survey is exclusively directed at international visitors. The bias for this assumption is not known and was probably greater during the COVID-19 pandemic in 2020 and 2021 than before and after the pandemic. During the pandemic there were almost only Icelandic residents travelling in Iceland. Icelanders travel mostly in the summer, and they hardly travel at all during the colder winter months (Bjarnadóttir, 2008; The Icelandic Tourist Board, 2023).

Number of Vehicles on the Icelandic Highway System

Vehicle counters operated along the highway system in Iceland by IRCA. They are inductive loop counters that count the number of vehicles passing per day. The primary purpose of IRCA's counters is to monitor traffic for maintenance and security purposes. This study analyses tourist traffic on a section of the Ring Road along the South Coast from Hvammur in the west to Smyrlabjörg in the east (see locations in Figure 2) using data from IRCA's vehicle counters. Along this stretch of road, the local population is sparse and there are few side roads; the many tourist sites and the tourist traffic thus constitute a significant proportion of the overall traffic. Around 78% of the traffic passing IRCA's vehicle counter at Lómagnúpur is tourists in rental cars (Guðmundsson, 2020). West of the Hvammur counter, traffic is more of local origin, as that area is more populated, and there are many side roads leading to the so-called uplands of the south. It would have been interesting to analyse the traffic at the whole Ring Road from IRCA's counters, but it was considered unreliable because the origin of the traffic is unclear and there are quite many side roads from the Ring Road outside of the south region. Along the South Coast there are two villages, Vík and Kirkjubæjarklaustur. The inhabitants of Vík and Kirkjubæjarklaustur (Figure 2) are likely to influence the numbers by driving in the region, and this addition has not been analysed. East of Jökulsárlón and the Smyrlabjörg counter, the traffic is also more local (Figure 2).

Seasonality Measures

This paper addresses seasonality in two ways:

- By computing the percentage of guests visiting the nature-based destinations during the summer and winter compared with the entire year.
- By computing the Gini coefficient at each site from monthly data.

In this analysis, the year is divided into two equal parts: summer and winter. Summer is comprised of the months May, June, July, August, September, and October, while winter includes January, February, March, April, November, and December. This division is made from a previous analysis of visitor numbers at nature-based destinations in southern and western Iceland. Previous analysis indicates that the summer traffic peaks in July and August but extends into the shoulder seasons at both ends (Thórhallsdóttir & Ólafsson, 2017). For this study, it was considered adequate to divide the year into these two seasons. For a more detailed analysis, the year could be divided into four seasons or even into intervals of months or weeks.

The Gini coefficient is the tool most often utilised to analyse seasonality (Duro, 2016). In this work, it serves as a numerical measure of the degree of inequality in visitation numbers to a site throughout the year. It is derived from the Lorenz curve that displays the cumulative frequency of ranked observations, starting with the lowest number. The Gini coefficient takes values from zero to one. The closer it is to zero, the less seasonality there is, and the closer it is to one, the greater the seasonality (Thórhallsdóttir & Ólafsson, 2017).

Results

Visitors departing Keflavík International Airport

There was a steady increase in the number of visitors to Iceland from 2015 to 2019. During this time, seasonality also decreased. Then in March 2020, COVID-19 hit Iceland, resulting in a decrease in visitor numbers and an increase in seasonality. In 2022, international tourism to Iceland began to recover from the pandemic and seasonality decreased (Table 2 and Table 3).

Table 2. *Number of departing passengers (in thousands) at Keflavík International Airport.*

Keflavík	2015	2016	2017	2018	2019	2020	2021	2022	2023
Summer	821	1.122	1.310	1.400	1.151	133	530	1.097	1.375
Winter	441	645	886	916	835	349	158	600	849
Total	1.262	1.767	2.196	2.316	1.986	482	688	1.697	2.224

Table 3. *Seasonality in departing visitors at Keflavík International Airport.*

Keflavík	2015	2016	2017	2018	2019	2020	2021	2022	2023
Summer	65%	63%	60%	60%	58%	28%	77%	65%	62%
Winter	35%	37%	40%	40%	42%	72%	23%	35%	38%
Gini	0.21	0.19	0.14	0.14	0.14	0.61	0.49	0.22	0.16

The Golden Circle

In this section, the data from Geysir, Gullfoss, and Þingvellir National Park is presented. In 2015, the visitor numbers at Þingvellir National Park were lower than at Geysir and Gullfoss, but between 2016 and 2019 the visitor numbers were similar. The annual visitor numbers at Þingvellir National Park began to recover after COVID-19 in 2022 and then reached the visitor numbers of 2016 (Table 4). Seasonality decreased at these sites from 2015 to 2019 and began to recover after the pandemic in 2022 (Table 5). Apart from the COVID-19 period, around two thirds of all departing visitors travelled to Geysir, Gullfoss, and Þingvellir National Park during their stay, independent of the season (Table 6).

Table 4. *Number of visitors (in thousands) at the nature-based destinations in the Golden Circle.*

		2015	2016	2017	2018	2019	2020	2021	2022
Geysir	Summer	579	795	885	957	831	-	-	-
	Winter	306	409	550	555	530	-	-	-
	Total	885	1.204	1.435	1.512	1.361	-	-	-
Gullfoss	Summer	572	785	869	943	822	-	-	-
	Winter	299	403	537	544	518	-	-	-
	Total	871	1.188	1.406	1.487	1.340	-	-	-
Þingvellir National Park	Summer	487	783	933	873	836	97	268	853
	Winter	209	391	593	541	500	204	69	346
	Total	696	1.174	1.526	1.414	1.336	301	337	1.199

Table 5. *Seasonality at the nature-based destinations in the Golden Circle.*

		2015	2016	2017	2018	2019	2020	2021	2022
Geysir	Summer	65%	66%	62%	63%	61%	-	-	-
	Winter	35%	34%	38%	37%	39%	-	-	-
	Gini	0.22	0.22	0.18	0.17	0.17	-	-	-
Gullfoss	Summer	66%	66%	62%	63%	61%	-	-	-
	Winter	34%	34%	38%	37%	39%	-	-	-
	Gini	0.22	0.22	0.18	0.18	0.17	-	-	-
Þingvellir National Park	Summer	70%	67%	61%	62%	63%	32%	79%	71%
	Winter	30%	33%	39%	38%	37%	68%	21%	29%
	Gini	0.26	0.22	0.15	0.17	0.18	0.52	0.45	0.27

Table 6. *The ratio between tourist numbers at the nature-based destinations in the Golden Circle and the number of departing passengers at Keflavík International Airport.*

		2015	2016	2017	2018	2019	2020	2021	2022
Geysir	Summer	71%	71%	68%	68%	72%	-	-	-
	Winter	69%	63%	62%	61%	63%	-	-	-
	Total	70%	68%	65%	65%	69%	-	-	-
Gullfoss	Summer	70%	70%	66%	67%	71%	-	-	-
	Winter	68%	62%	61%	59%	62%	-	-	-
	Total	69%	67%	64%	64%	67%	-	-	-
Þingvellir National Park	Summer	59%	70%	71%	62%	73%	73%	50%	78%
	Winter	47%	61%	67%	59%	60%	58%	44%	58%
	Total	55%	66%	70%	61%	67%	62%	49%	71%

South and Southeast

In this section, data from Seljalandsfoss, Dyrhólaey, Reynisfjara, Skaftafell, Jökulsárlón, and Vestrahorn is presented. In 2018 and 2019, Seljalandsfoss and Jökulsárlón were the most visited of these sites. Vestrahorn was less visited than the other sites, but the visitor numbers demonstrated a significant increase in those years over 2015 (Table 7). In 2018 and 2019, the ratio between seasons was similar at Seljalandsfoss, Reynisfjara, and Jökulsárlón, with around 65% of their visitors arriving in the summer; in 2019. Seasonality increased during the pandemic but decreased again in 2022 (Table 8). Apart from the COVID-19 period, around 40% of all departing visitors travelled to Jökulsárlón during their stay. In 2022, this ratio was 50%. In 2018 and 2019, around 50% of departing visitors travelled to Seljalandsfoss. This ratio was lower at the other sites (Table 9).

Table 7. *Number of visitors (in thousands) at the nature-based destinations on the South Coast travel route.*

		2015	2016	2017	2018	2019	2020	2021	2022
Seljalandsfoss	Summer	-	-	-	823	720	-	-	-
	Winter	-	-	-	392	362	-	-	-
	Total	-	-	-	1.215	1.082	-	-	-
Dyrhólaey	Summer	-	-	-	391	347	86	214	341
	Winter	-	-	-	146	138	58	35	95
	Total	-	-	-	537	485	144	249	436
Reynisfjara	Summer	-	-	-	572	533	164	350	-
	Winter	-	-	-	290	303	130	97	-
	Total	-	-	-	862	836	294	447	-
Skaftafell	Summer	370	498	545	582	505	148	332	461
	Winter	63	123	190	215	189	70	46	128
	Total	433	621	735	797	694	218	378	589
Jökulsárlón	Summer	406	539	595	658	617	206	429	603
	Winter	105	194	288	302	319	132	93	242
	Total	511	733	883	960	936	338	522	845
Vestrahorn	Summer	40	56	68	106	124	48	108	153
	Winter	14	17	26	36	44	24	19	41
	Total	54	73	94	142	168	72	127	194

Table 8. *Seasonality at the nature-based destinations on the South Coast travel route.*

		2015	2016	2017	2018	2019	2020	2021	2022
Seljalandsfoss	Summer	-	-	-	68%	67%	-	-	-
	Winter	-	-	-	32%	33%	-	-	-
	Gini	-	-	-	0.24	0.23	-	-	-
Dyrhólaey	Summer	-	-	-	73%	72%	60%	86%	78%
	Winter	-	-	-	27%	28%	40%	14%	22%
	Gini	-	-	-	0.31	0.31	0.53	0.51	0.36
Reynisfjara	Summer	-	-	-	66%	64%	56%	78%	-
	Winter	-	-	-	34%	36%	44%	22%	-
	Gini	-	-	-	0.22	0.19	0.42	0.41	-
Skaftafell	Summer	85%	80%	74%	73%	73%	68%	88%	78%
	Winter	15%	20%	26%	27%	27%	32%	12%	22%
	Gini	0.47	0.39	0.32	0.31	0.31	0.54	0.53	0.36
Jökulsárlón	Summer	79%	74%	67%	69%	66%	61%	82%	71%
	Winter	21%	26%	33%	31%	34%	39%	18%	29%
	Gini	0.40	0.33	0.25	0.25	0.23	0.49	0.47	0.28
Vestrahorn	Summer	74%	76%	72%	75%	74%	67%	85%	79%
	Winter	26%	24%	28%	25%	26%	33%	15%	21%
	Gini	0.34	0.34	0.30	0.32	0.32	0.38	0.48	0.36

Table 9. *The ratio between tourist numbers at the nature-based destination on the South Coast travel route and the number of departing passengers at Keflavík International Airport.*

		2015	2016	2017	2018	2019	2020	2021	2022
Seljalandsfoss	Summer	-	-	-	59%	63%	-	-	-
	Winter	-	-	-	43%	43%	-	-	-
	Total	-	-	-	52%	54%	-	-	-
Dyrhólaey	Summer	-	-	-	28%	30%	65%	40%	31%
	Winter	-	-	-	16%	17%	17%	22%	16%
	Total	-	-	-	23%	24%	30%	36%	26%
Reynisfjara	Summer	-	-	-	41%	46%	123%	66%	-
	Winter	-	-	-	32%	36%	37%	61%	-
	Total	-	-	-	37%	42%	61%	65%	-
Skaftafell	Summer	45%	44%	42%	42%	44%	111%	63%	42%
	Winter	14%	19%	22%	23%	23%	20%	29%	21%
	Total	34%	35%	34%	34%	35%	45%	55%	35%
Jökulsárlón	Summer	49%	48%	45%	47%	54%	155%	81%	55%
	Winter	24%	30%	33%	33%	38%	38%	59%	40%
	Total	40%	41%	40%	41%	47%	70%	76%	50%
Vestrahorn	Summer	5%	5%	5%	8%	11%	36%	20%	14%
	Winter	3%	3%	3%	4%	5%	7%	12%	7%
	Total	4%	4%	4%	6%	8%	15%	18%	11%

The South Coast Travel Route

In this section, the mobility patterns in 2016, 2019, and 2022 along the South Coast travel route are presented for further clarification, utilising IRCA´s existing network of vehicle counters on the Ring Road. These years were selected to see the development in traffic before and after the pandemic. The location of IRCA's counters compared to the study sites are found in Figure 2. There was a malfunction in IRCA's Mýrdalssandur counter in 2016, therefore there is no data for the summer of 2016 (Figure 3).

In 2016, there was less traffic along the South Coast travel route compared to 2019 and 2022. Within each year the summer traffic between Hvammur and Reynisfjall was relatively stable. The Reynisfjall counter is between Reynisfjara and the village Vík (Figure 2). Independent of year and season, the traffic decreased between the Reynisfjall counter and Mýrdalssandur counters, by around 50%. Within each year, the traffic levels at the Mýrdalssandur and Eldhraun counters were similar (Figure 3 and Figure 4). Independent of year, the traffic decreased further between Eldhraun and Lómagnúpur, around 11% in summer and 15% in winter. There was a decrease between Kvísker and Smyrlabjörg. In 2016, the decrease was 20% in summer and 32% in winter. In 2019 and 2022, the decrease was around 25% in summer and 40% in winter.

It is estimated that around 60% of vehicles driving the highway past the Kvísker counter went to Jökulsárlón, independent of season. That estimation is based on the number of vehicles driving the highway in both directions, as it is not known in which direction vehicles were driving. There is an access road to Jökulsárlón, therefore vehicles to this site pass the counter twice. The data for Jökulsárlón has therefore been divided by two.

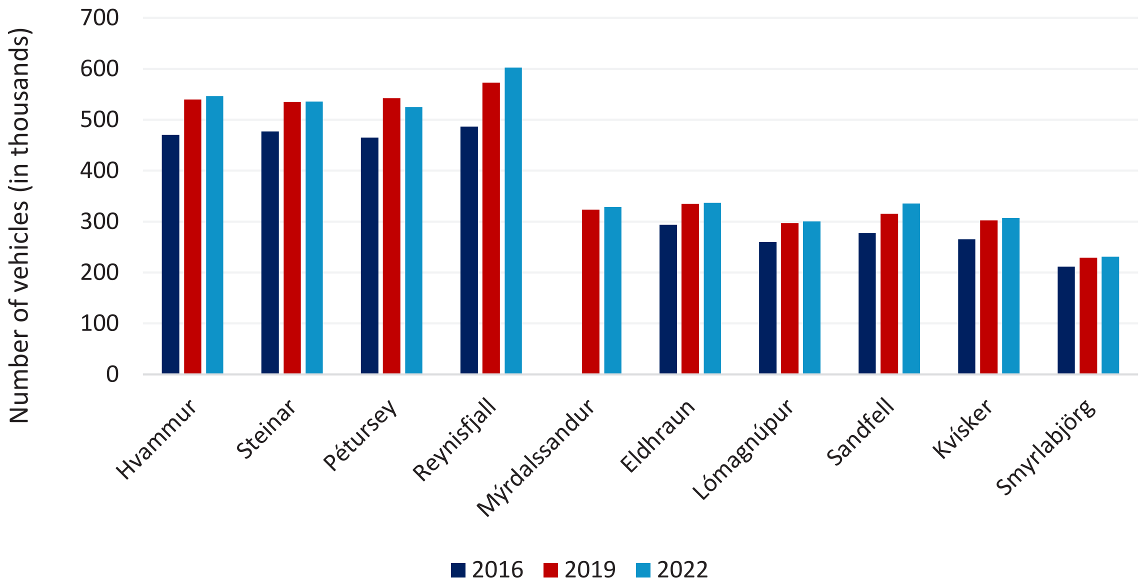

Figure 3. *Number of vehicles along the South Coast travel route in the summers of 2016, 2019, and 2022 (The Icelandic Road and Coastal Administration, 2020).*

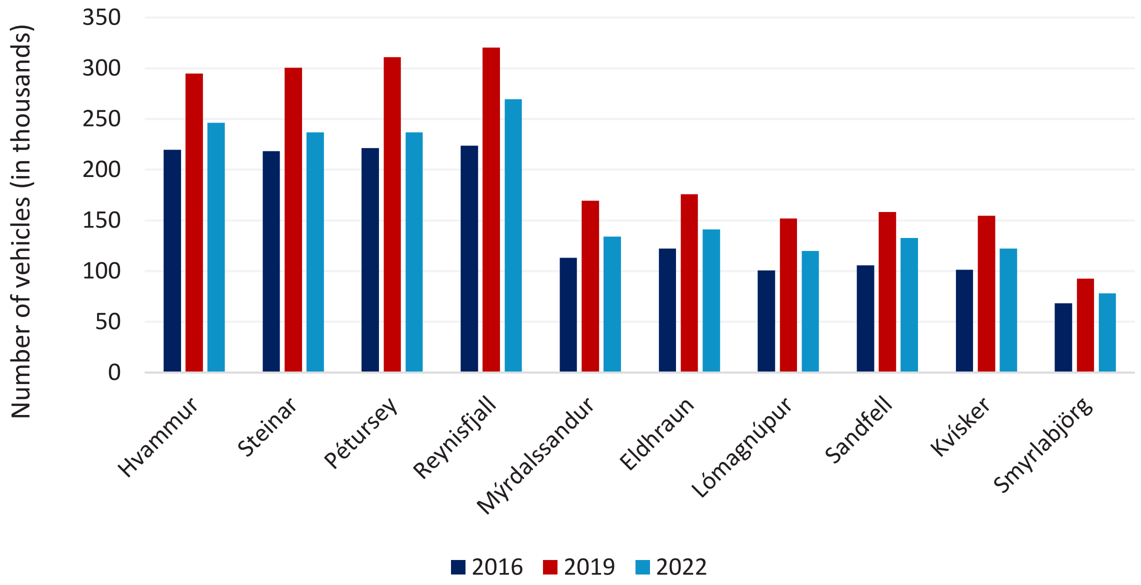

Figure 4. *Number of vehicles along the South Coast travel route in the winters of 2016, 2019, and 2022 (The Icelandic Road and Coastal Administration, 2020).*

North and Northwest

In this section, the data from Hvítserkur, Goðafoss, Námaskarð, Ásbyrgi, and Dettifoss is presented. The COVID-19 effect was very visible at Ásbyrgi and Dettifoss in 2020 and 2021; however, numbers in 2022 increased and were close to the numbers before the pandemic. Námaskarð was the most visited site in the region in 2019, with 467,000 visitors, followed by Goðafoss, with 420,000 visitors, and Dettifoss, with 370,000 visitors. Hvítserkur in the northwest and Ásbyrgi in the northeast had lower visitor numbers (Table 10). Seasonality decreased from 2015 to 2019. In 2019, around 85% of the visitors that went to Námaskarð, Goðafoss, and Hvítserkur went during the summer, and the Gini coefficient at these sites was 0.46. The Gini coefficient at Námaskarð decreased from 0.51 in 2016. In 2019, 93% of visitors to Dettifoss went during the summer. In 2022, seasonality at Ásbyrgi and Dettifoss was lower than before the pandemic (Table 11). Using the data from Keflavík International Airport, it appears that approximately 24% of departing visitors visited Námaskarð in 2019, while 21% visited Goðafoss, mostly during the summer (Table 12).

Table 10. *Number of visitors (in thousands) at the nature-based destinations in the north and northwest.*

		2015	2016	2017	2018	2019	2020	2021	2022
Hvítserkur	Summer	-	79	104	112	123	36	-	-
	Winter	-	3	9	15	20	1	-	-
	Total	-	82	113	127	143	37	-	-
Goðafoss	Summer	219	342	363	377	354	-	-	-
	Winter	27	28	55	67	66	-	-	-
	Total	246	370	418	444	420	-	-	-
Námaskarð	Summer	-	362	421	425	398	-	-	-
	Winter	-	42	66	73	69	-	-	-
	Total	-	404	487	498	467	-	-	-
Ásbyrgi	Summer	-	103	118	108	111	80	105	113
	Winter	-	3	6	6	6	2	3	7
	Total	-	106	124	114	117	82	108	120
Dettifoss	Summer	214	-	368	331	344	107	226	310
	Winter	-	-	47	39	27	2	8	34
	Total	-	-	415	370	371	109	234	344

Table 11. *Seasonality at the nature-based destinations in the north and northwest.*

		2015	2016	2017	2018	2019	2020	2021	2022
Hvítserkur	Summer	-	96%	92%	88%	86%	98%	-	-
	Winter	-	4%	8%	12%	14%	2%	-	-
	Gini	-	0.57	0.53	0.49	0.46	0.72	-	-
Goðafoss	Summer	89%	92%	87%	85%	84%	-	-	-
	Winter	11%	8%	13%	15%	16%	-	-	-
	Gini	0.57	0.53	0.50	0.46	0.46	-	-	-
Námaskarð	Summer	-	90%	87%	85%	85%	-	-	-
	Winter	-	10%	13%	15%	15%	-	-	-
	Gini	-	0.51	0.47	0.46	0.46	-	-	-
Ásbyrgi	Summer	-	97%	95%	95%	95%	98%	97%	94%
	Winter	-	3%	5%	5%	5%	2%	3%	6%
	Gini	-	0.64	0.63	0.61	0.61	0.72	0.66	0.58
Dettifoss	Summer	-	-	89%	89%	93%	98%	97%	90%
	Winter	-	-	11%	11%	7%	2%	3%	10%
	Gini	-	-	0.51	0.53	0.57	0.74	0.63	0.52

Table 12. *The ratio between tourist numbers at the nature-based destinations in the north and northwest and the number of departing passengers at Keflavík International Airport.*

		2015	2016	2017	2018	2019	2020	2021	2022
Hvítserkur	**Summer**	-	7%	8%	8%	11%	27%	-	-
	Winter	-	0.5%	1%	2%	2%	-	-	-
	Total	-	5%	5%	5%	7%	8%	-	-
Goðafoss	**Summer**	27%	30%	28%	27%	31%	-	-	-
	Winter	6%	4%	6%	7%	8%	-	-	-
	Total	19%	21%	19%	19%	21%	-	-	-
Námaskarð	**Summer**	-	32%	32%	30%	35%	-	-	-
	Winter	-	6%	7%	8%	8%	-	-	-
	Total	-	23%	22%	21%	24%	-	-	-
Ásbyrgi	**Summer**	-	9%	9%	8%	10%	60%	20%	10%
	Winter	-	0.5%	1%	1%	1%	0.5%	2%	1%
	Total	-	6%	6%	5%	6%	17%	16%	7%
Dettifoss	**Summer**	26%	-	28%	24%	30%	81%	43%	28%
	Winter	-	-	5%	4%	3%	1%	5%	6%
	Total	-	-	19%	16%	19%	23%	34%	20%

Southwest, West and Westfjords

In this section, data from four nature-based destinations in the southwest, west, and Westfjords is presented: the Bridge Between Continents, Hraunfossar, Djúpalónssandur, and Látrabjarg. Table 13 indicates the development of visitor numbers at these four sites. The effect of the pandemic is very clear in 2020 and 2021, but the visitor numbers in 2022 were close to pre-pandemic levels. Seasonality increased during the pandemic but decreased in 2022 (Table 14). Even though the Bridge Between Continents is very close to the main airport, it is not highly visited (Table 15).

Table 13. *Number of visitors (in thousands) at the nature-based destinations in the southwest, west, and Westfjords.*

		2015	2016	2017	2018	2019	2020	2021	2022
Bridge Between Continents	**Summer**	-	-	124	126	116	37	75	127
	Winter	-	-	52	56	49	26	18	42
	Total	-	-	176	182	165	63	93	169
Djúpalónssandur	**Summer**	84	113	140	154	166	49	106	160
	Winter	9	20	34	37	43	15	11	28
	Total	93	133	174	191	209	64	117	188
Hraunfossar	**Summer**	136	186	224	201	196	74	109	160
	Winter	17	37	57	56	55	23	20	39
	Total	153	223	281	257	251	97	129	199
Látrabjarg	**Summer**	-	-	-	61	61	33	46	56
	Winter	-	-	-	3	3	1	1	1
	Total	-	-	-	64	64	34	47	57

Table 14. *Seasonality at the nature-based destinations in the southwest, west, and Westfjords.*

		2015	2016	2017	2018	2019	2020	2021	2022
Bridge Between Continents	**Summer**	-	-	70%	69%	70%	59%	81%	75%
	Winter	-	-	30%	31%	30%	41%	19%	25%
	Gini	-	-	0.29	0.26	0.28	0.41	0.44	0.32
Djúpalónssandur	**Summer**	90%	85%	80%	80%	79%	77%	90%	85%
	Winter	10%	15%	20%	20%	21%	23%	10%	15%
	Gini	0.55	0.47	0.41	0.40	0.40	0.55	0.54	0.45
Hraunfossar	**Summer**	89%	83%	80%	78%	78%	76%	85%	81%
	Winter	11%	17%	20%	22%	22%	24%	15%	19%
	Gini	0.53	0.45	0.40	0.38	0.38	0.48	0.47	0.39
Látrabjarg	**Summer**	-	-	-	96%	96%	97%	98%	97%
	Winter	-	-	-	4%	4%	3%	2%	3%
	Gini	-	-	-	0.62	0.64	0.73	0.66	0.64

Table 15. *The ratio between tourist numbers at the nature-based destinations in the southwest, west, and Westfjords and the number of departing passengers at Keflavík International Airport.*

		2015	2016	2017	2018	2019	2020	2021	2022
Bridge Between Continents	**Summer**	-	-	10%	9%	10%	28%	14%	12%
	Winter	-	-	6%	6%	6%	7%	11%	7%
	Total	-	-	8%	8%	8%	13%	14%	10%
Djúpalónssandur	**Summer**	10%	10%	11%	11%	14%	37%	20%	15%
	Winter	2%	3%	4%	4%	5%	4%	7%	5%
	Total	5%	7%	8%	8%	11%	13%	17%	11%
Hraunfossar	**Summer**	17%	17%	17%	14%	17%	55%	21%	15%
	Winter	4%	6%	6%	6%	7%	7%	12%	6%
	Total	12%	13%	13%	11%	13%	20%	19%	12%
Látrabjarg	**Summer**	-	-	-	5%	5%	25%	9%	5%
	Winter	-	-	-	0.2%	0.2%	0.2%	1%	0.2%
	Total	-	-	-	3%	3%	7%	7%	3%

Discussion

Mobility in Time and Space to Visit Unique Attractions

The analysis of the mobility patterns of international visitors in Iceland in this study has both theoretical and practical value. Time geography has been used to observe the connections between space, time, and mobility (Zillinger, 2007). This study reveals the connection between space, time, and mobility as manifested in seasonality at various sites in Iceland. Visitors have limited time during their holidays, which determines how far they can travel. During the summer, when visitors have more time to travel, they stay longer in the country and explore regions further away from Keflavík International Airport, the main gateway to Iceland. This study therefore illustrates how spatial mobility is dependent on time. The study also underscores how the uniqueness of attractions can override the barrier that distance creates for visitation. Furthermore, the study reveals the importance of access to regions and sites and of an efficient transportation system as tourists will go elsewhere if the transportation system is inconvenient (Qian Pei et al., 2022).

Jökulsárlón is a unique site with good access and efficient transportation system that is highly visited throughout the year although it is situated 380 km from Keflavík International Airport. It is considered a must-see site that international tourists should visit, independent of time. This situation relates to the distance decay concept, as unique attractions are more likely to overcome the distance decay factor. Goðafoss, Námaskarð, Dettifoss, and Ásbyrgi are further from the main gateway, around 550 km away; however, these nature-based destinations have higher visitor numbers than the nature-based destinations in the west, Hraunfossar and Djúpalónssandur, and the Bridge Between Continents, which are much closer to the Keflavík International Airport. This indicates that greater distance is not the main reason for fewer visitors; the explanation also lies in the attraction itself and its location. As a black sand beach, Djúpalónssandur is a similar site to Reynisfjara on the South coast. Goðafoss and Dettifoss in the north are spectacular waterfalls, not unlike Gullfoss in the vicinity of the capital area. Both Námaskarð and Geysir are geothermal areas. What benefits Reynisfjara compared to Djúpalónssandur is its location on the South Coast travel route. The same can be said of Gullfoss and Geysir. Geographical location is important, and if multiple destinations provide similar experiences, the ones closest to the starting point are likely to be the most visited (Hooper, 2015). Along the South Coast is a chain of nature-based destinations, that benefits from being between the capital area and Jökulsárlón. The nature-based destinations in the other regions may suffer from having too extended "boring bits" in between as Koster and Carson (2019) describe the rural areas that lie in between major metropolitan core or unique natural attractions. In these areas, tourism has not become an important industry of employment, they may be considered drive through areas, the infrastructure is weak and there is a more explicit seasonality (Carson et al., 2020).

It is interesting to analyse the tourism mobility in Iceland during the years 2020 and 2021, when there was hardly any international tourism due to the COVID-19 pandemic. The pandemic hit Iceland in February/March 2020, and in April, the country was closed for tourists (Figure 1). However, this did not change the mobility pattern in Iceland. The results indicate that residents in Iceland visited the same sites as international visitors did before the pandemic. Before the summer of 2020, the Icelandic authorities gave all residents in Iceland older than 18 a travel gift in the amount of five thousand ISK. This was done to influence Icelanders to travel domestically that summer. This gift was then repeated in 2021. During the summer of 2020, Jökulsárlón was the most visited site, second most visited site was Reynisfjara and third, Skaftafell, all of which are nature-based destinations along the South Coast travel route. During the winter of 2020, Jökulsárlón was slightly more visited than Reynisfjara, and next came Þingvellir National Park, which is quite popular among domestic travellers in the capital area as a day trip. Most Icelanders live in the capital area: in 2019, 64% of the nation lived there. The results from 2021 were quite similar to the 2020 results. These results indicate the importance of an attraction itself if a site is to attract visitors. Distance appears to be less relevant.

Unfortunately, the ratio between international and domestic visitors at the sites is not known. It has been stated that the number of inhabitants in Iceland is outnumbered by international visitors. The bias is considered to be greater during the summer than winter, as Icelanders mostly travel domestically during the summer. This bias is also more apparent at some sites compared to others. Therefore, when the number of departures from Keflavík International Airport was compared to a given individual site, it was decided to assume that all visitors were foreign. The bias is therefore not known, but it was clearly much greater during the pandemic period than before or after. The ratio between Icelandic residence and international visitors is something that needs to be considered for future research.

Sustainable Tourism Planning and Management in Iceland

The practical implications of this study are significant for sustainable tourism planning and management in Iceland. The findings provide valuable information for determining the necessary services and infrastructure at nature-based destinations. Additionally, the results provide valuable information on regional seasonality. All of this, including data on number of visitors, is important when planning and managing for sustainable tourism (Lew & McKercher, 2006). Moreover, the findings of this study can be valuable for tourism management beyond Iceland, particularly in the Arctic regions, where nature and nature-based attractions dominate, and there is high seasonality and uneven regional distribution of visitors and revenues.

This study indicates that both the spatial distribution and seasonality of tourism in Iceland work against the sustainability goals of the government. Official policy has for years been to distribute and diversify the tourist flow to protect nature and ensure a positive experience for both locals and international visitors (The Ministry of Industries and Innovation, 2015). As far as seasonality is concerned, however, this policy has not been successful. The number of attractions in the south and their uniqueness, as well as their relative proximity to the main gateway, mean that it will be a challenge to aim for a more equal distribution of tourist flow throughout Iceland, particularly during the winter season when the main road may close and the access roads to the sites may be closed for snow and ice. This high regional seasonality is also seen elsewhere in the Nordic countries, especially in the Arctic regions (Lundmark & Carson, 2020).

The results demonstrate that Keflavík International Airport plays a significant role in shaping the spatial distribution of tourism in Iceland. Altering this pattern would require strengthening other gateways, such as Akureyri in the north and Egilsstaðir in the east. While strengthening these airports might have some effect, the question arises as to whether the attraction of the sites in the north and east is strong enough to bring substantial numbers of visitors, even with reduced distances. It is important to recognize the attraction of the nature sites in the south and the proximity of Reykjavík, the only city in Iceland, with its diverse cultural and social attractions and services. According to Carson et al. (2020), urban areas are often perceived as offering better value for money and more choices. This is also seen in the Arctic regions (Müller et al., 2020), where visitors tend to stay in the urban centres and take day-tours to nature-based destinations from there (Carson et al., 2020). Therefore, it is important to analyse tourism mobility patterns in the Arctic regions from nature-based destinations, not overnight stays (Runge et al., 2020). Several attempts have been made to begin international flights from Akureyri Airport in the north of Iceland, and all have failed. This indicates that for such flights to be commercially successful, more is needed than the local market. In October 2023, Easy Jet began to fly to Akureyri Airport from London Gatwick Airport, with flights that are scheduled until March 2024 (Daðason, 2023). It remains debatable whether the nature sites that are the attractions in the north are strong or unique enough to counterbalance other factors. However, well-established international airline sees an opportunity to schedule flights to the north of Iceland indicates that further bolstering of attractions in the region is likely to take place, and that may change the dynamics of tourist mobility to some degree. Developing other sites would require significant investment in infrastructure and services. Therefore, it is worth considering whether distributing the visitor flow should remain a core agenda in Icelandic tourism management.

Conclusions

This study analysed the mobility patterns of international visitors in Iceland based on visitor numbers at nature-based destinations. The results provide valuable information on tourism flow in time and space in Iceland. Awareness of these factors is important when planning and managing sustainable tourism and evaluating the effectiveness of existing policies. This paper focuses on the temporal and spatial mobility of international visitors starting and ending their travel at Keflavík International Airport. Within the limited timeframe they have during summer or winter, these visitors typically set out to visit numerous nature sites that are predominantly located in the rural south and along the South Coast before returning to the airport to catch a flight home. It would have been interesting to further analyse the South Coast travel route, but it was not possible with this dataset. However, in light of how important that travel route is to the tourism industry, further research should be done on this stretch of the highway.

The first research question asks about the actions that Icelandic tourism authorities have taken to reduce regional seasonality. Apart from the pandemic years, Icelandic tourism authorities have succeeded in reducing seasonality in the country. There are policies for reducing regional seasonality and making tourism more sustainable economically, socially, and for the environment. Sustainability has been an aim of the Icelandic tourism authorities for decades but has not been successful outside of the most popular areas. So far, it appears that post-COVID-19 tourism mobility is following similar patterns to before the pandemic.

The second research question asks about the method of using visitor numbers at nature-based destinations to plan and manage sustainable tourism in Iceland. In a country such as Iceland, where the main attraction is nature and therefore nature-based destinations that are distributed around the island, this method provides a good indication of tourism mobility patterns. By analysing the mobility patterns for these attractions, where people travel can be determined. In Iceland, this form of analysis is more reliable than overnight stay data, as overnight stay data only provides an indication of where visitors stay overnight, not where they visit during the day. It is known that Reykjavík is the most visited site in Iceland and serves as a basecamp for nature-based destinations, but the overnight data cannot inform us about which actual sites these guests visit during the daytime. This is an important consideration for nature protection as many day-time visits take place in protected areas. The day-visitors set pressure on the nature-based destination that is important to monitor directly for the protection and the management of these sites.

The data and analysis in this paper are expected to be useful for the Icelandic government in managing tourism in Iceland and planning its future. The study indicates that for international visitors in Iceland, the attraction of a site is more important than its distance from their starting point. What exactly influences the attractiveness of individual sites for tourists needs to be further researched in more depth than has thus far been the case.

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Paper 4

Sustainable Tourism Planning and Management

A Research Method to Analyse Mobility Patterns in Rural Areas

Abstract:

The aim of the paper is to test and evaluate an innovative research method for analysing tourism mobility patterns in rural peripheral areas. The mobility patterns relate to the management of services, such as transportation and diverse infrastructure, that is important for sustainable tourism planning and management. Two sensors that detect Bluetooth signals from smart devices were strategically positioned east and west of the glacial lagoon Jökulsárlón, a popular nature-based destination located in Iceland's rural southeast. The method gives insights into visitor flow, traffic, crowding and sequential movement. It offers an economic means of gathering extensive data on tourism mobility in rural areas that can inform for sustainable tourism planning and management.

The study identified seasonality in mobility patterns in the area. The visitors stayed on average two hours in the area, longer during the winter. During the winter the mobility patterns were characterized by the west to east movement followed by a return flow westward. During the summer, the west to east movement was dominant, indicating that the visitors were driving around the island. The research method and its results are important for managers of rural peripheral sites when planning for sustainable tourism.

Keywords: Research method; Bluetooth sensors; Mobility patterns in time and space; Sustainable tourism planning and management; Iceland.

1. Introduction

In recent years, the Arctic regions have gained popularity as tourist destinations, notably Lapland in northern Finland, Northern Norway and Iceland (Maher et al., 2022). In Iceland, international tourist arrivals have increased greatly, in 2010, 459,000 visitors came to Iceland, but in 2018 they were 2.3 million. There was a decrease in numbers during the Covid-19 pandemic that has now recovered (The Icelandic Tourist Board, 2024). The great increase in visitor numbers to Iceland from 2010 to 2018 prompted Icelandic authorities to continue to focus on sustainable tourism management in their policymaking (Jóhannesson et al., 2010). The focus has been on distributing the flow of visitors and associated revenues more evenly across regions, while protecting the main tourist attraction: nature, as well as nature-based destinations. In the most recent policy making, the Icelandic tourism authorities have stated that the overall objective is to be leading in sustainable tourism in the world (Government of Iceland, n.d.).

Due to positive economic impacts of the tourism industry, tourism is often considered as a vehicle for regional development, especially in declining rural areas (Kauppila et al., 2009). However, tourism in the Arctic regions often experiences high regional seasonality. Visitors also tend to stay in urban centers (Carson et al., 2020) and take day-tours from there to the peripheral rural areas (Maher et al., 2022). This results in uneven distribution of revenues and potential economic leakage from the rural area to the center (Huijbens, 2022; Maher et al., 2022; Rantala et al., 2019).

Therefore, even for the positive economic impacts from tourism, it may at the same time also have negative impacts (Árnason & Kolbrúnardóttir, 2019), on nature, and on the local community, especially in rural areas (Butler, 1999). These different and complex effects from tourism makes it essential to have various data to be able to plan and manage tourism sustainably for the future (Lew & McKercher, 2006). One important puzzle is to know the mobility patterns of tourists in time and space as it predicts for various infrastructure and services.

Collecting data manually on tourism mobility patterns in rural and peripheral areas is both time-consuming and expensive. Consequently, there is significant value in using data from big data sources, such as financial transactions, purchases and online actions. This study aims to evaluate the use of Bluetooth sensors, to analyse tourism mobility patterns in both temporal and spatial dimensions within a rural context. The selected research site is the glacial lagoon Jökulsárlón, located in southeast Iceland (Figure 1). Despite its remote location, approximately 380 km from the capital region and the main gateway into the country, Keflavík International Airport, the site is highly accessible as it is situated along the Ring Road, the primary highway encircling Iceland, and is a major tourist attraction.

The research method is innovative as it has not been used to predict mobility patterns in rural areas before. Two sensors that detect Bluetooth signals from smart devices were set up beside the Ring Road, west and east of Jökulsárlón (Figure 2). Bluetooth sensors collect data directly from smart devices. The advantage of collecting the data directly is that it reduces the risk of human error associated with surveys, which are often subject to memory bias. Also, Bluetooth sensors offer real-time data on mobility patterns, enabling researchers to observe changes and trends as they occur.

Two vehicle counters were placed on the highway adjacent to each Bluetooth sensor, ensuring an accurate estimation of the sample size. Additionally, three supplementary vehicle counters at Jökulsárlón, Breiðá and Þröng, operated by Vatnajökull National Park, were used, to provide a more comprehensive analysis of mobility patterns. This dataset was subsequently integrated with overnight stay data compiled by Statistics Iceland to further enhance the analysis.

The Bluetooth sensors give information about when the visitors came during the day, how long they stayed, but also from which direction the visitors came and in which direction they went. This data along with data on visitor numbers is basic information for planning and managing sustainable tourism. It supports decision-making regarding transportation infrastructure, the sizing of parking facilities, and the development of other essential services to ensure sustainable tourism practices.

The Bluetooth method has been widely tested in urban environments but not in rural peripheral areas, such as in the Jökulsárlón area. Therefore, even though the method has been widely used in urban environments with the challenges that the urban holds, it has not been used in rural environments. This makes it an innovative research method for the rural environments. The challenges in the urban and rural environment are very different. Lack of electricity to power the sensors in the rural areas is a big challenge. In this case the sensors were powered by batteries that needed to be changed regularly but later they were powered with solar cells. In the rural area there is no noise in the data from other devices that interrupt the counting, such as in urban environments. Still other challenges are the same between the rural and the urban environments, such as who is being registered, a visitor, staff, residents or someone else. This is a bias in the sample that can never be avoided.

To fulfil the aim of the paper the following research questions will be addressed:

- How valuable is the use of Bluetooth sensors as a research method for analysing tourism mobility in peripheral areas?
- How can the analysis of mobility patterns in time and space at Jökulsárlón contribute to planning and management strategies for sustainable tourism in Iceland?

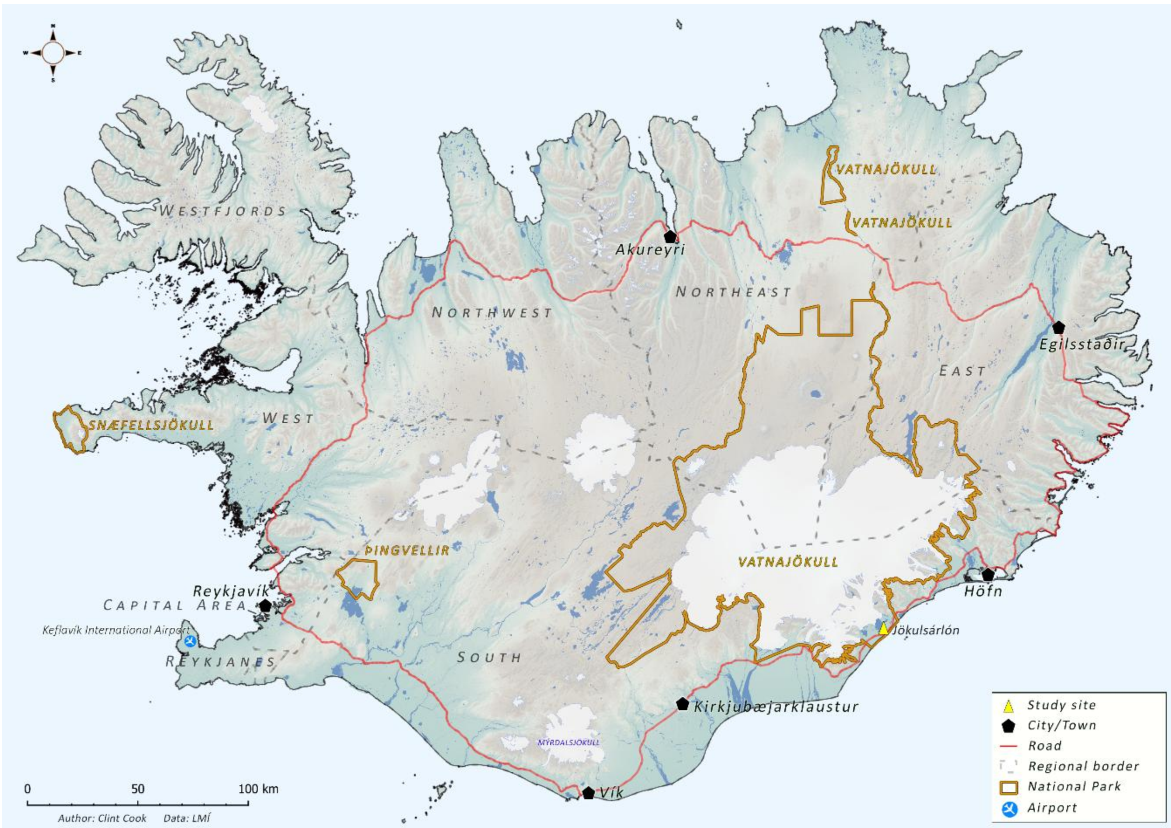

Figure 1. Map of Iceland.

2. 2. Theoretical Framework

Mobility Patterns

Mobility patterns of tourists relates to how services, such as transportation and diverse infrastructure are planned and managed (De Cantis et al., 2015; Leiper, 1979; Shoval & Isaacson, 2009), making transportation in its broadest sense (Scuttari et al., 2013), e.g., roads and airports (Runge et al., 2020), accessibility to a destination, uniqueness of an attraction (McKercher & Lew, 2003), and distance of travel (McKercher, 2018), key factors in tourism mobility planning and management.

Advancements in transportation technology have expanded spatial mobility, a travel that took one or two days before, can now be completed in hours (Hall, 2005). Then, the use of private and rental cars has increased, allowing tourists to travel faster, and therefore further, in less time than was previously possible (Dickinson et al., 2013), giving them more flexibility and autonomy in planning their trips compared to using public transport (Beeco et al., 2013). The autonomy of unpredictable visitors can be challenging for tourism managers that aim for sustainable tourism management planning, making it even more important to know their mobility patterns.

The internet and smart devices, such as the mobile phone, have had a great influence on tourism mobilities (Urry & Larsen, 2011). The smart devices and social media have made travelers more independent during their travels and the daily schedule can easily be made on the go with networked connections between people in social media (Dickinson et al., 2012). The data from smart devices and social media can be used to analyse tourism mobility (Fisher et al., 2018; Runge et al., 2020). These data sources are becoming increasingly important for peripheral rural areas, where there is a lack of staff and financial capacity to collect data manually to analyse tourism mobility (Runge et al., 2020).

Peripheral areas often lack various infrastructures, and facilities such as accommodations and restaurants, but also an efficient transportation system. Therefore, the tourists tend to stay overnight in urban areas and take day tours from there. Urban areas are also often perceived as offering better value for money, more choices, and higher standards compared to peripheral rural areas (Carson et al., 2020). This often results in uneven regional distribution of visitors and consequently in uneven distribution of revenues (Carson et al., 2020; Huijbens, 2022; Maher et al., 2022; Müller et al., 2020; Rantala et al., 2019). This preference for urban areas is prevalent in various Arctic countries and other regions characterized by long distances between service hubs and natural attractions (Müller et al., 2020).

Tourism authorities often lack comprehensive data on tourists' daily activities and destinations. It is known where they overnight but not where they go during the day (Runge et al., 2020). As said before, the main attraction of the Arctic is nature and therefore nature-based destinations (Maher et al., 2022). An important consequence of an urban center serving as a basecamp is that excursions rarely go beyond an easy commuting distance from the city (Carson et al., 2020). Day tours from urban areas reduce the time and money spent in rural areas and affect the potential for sustainable development of tourism in rural regions. Channeling visitors into specific well managed sites may be beneficial for the sensitive Arctic flora and fauna (Runge et al., 2020).

Mobility Research

Analysing tourism mobility in time and space in rural and peripheral areas with traditional methods can be time consuming and expensive in practice. Traditional methods for mobility analysis are for example; interviews, surveys and direct observations (Orellana et al., 2012). Therefore, researchers have in recent years seen opportunities in using new tracking methods from Big Data sources. They are much easier and cheaper to use than the traditional methods previously employed. Big Data for transportation involves data from multiple data sources such as from mobile devices, like smart phones, and applications installed on mobile devices, location-based services, and navigation GPS systems, for example data derived from mobile devices and social media, (Fisher et al., 2018). Then, as in this study, data from Bluetooth/Wi-Fi sensors have increasingly been used for tracking visitor movements both at indoor and outdoor locations; e.g., at airports to estimate the waiting time (Bullock et al., 2010; Gheorghiu et al., 2021), and in urban environments (Versichele et al., 2014), e.g., at mass events, within cities, shopping centers (Oosterlinck et al., 2017), in museums (Yoshimura et al., 2017), but also for traffic management (Versichele, Neutens, Goudeseune, et al., 2012).

Using data from Big Data sources raises several ethical questions about the data source as the data is often collected without the consent of the individual (Hardy, 2020b). Therefore, ethical considerations are crucial when working with this kind of tracking data (Hardy, 2020a). Collecting data without one's consent has its advantages and disadvantages. Because the individual has no knowledge about their participation in a research project it does not influence their travel. Therefore, their awareness does not bias the results as may happen in traditional surveys. Then the data gives no socio-demographic data, or data on tourists' preferences. Therefore, it is hard or even impossible to differentiate between locals and tourists. As this may be considered a disadvantage, it is also an advantage as the lack of socio-demographic data makes the dataset less identifiable (Hardy, 2020c).

It is critical to validate the integrity and the consistency of Big Data analytics to a known consistent dataset. In the case of transport analytics, the data should be validated against an existing data set that has been confirmed for accuracy, for example data from vehicle counters or trail counters (Streetlight, 2019).

Bluetooth sensors

The Bluetooth signal is low in power, robust and low cost (Hardy, 2020c). It is a short range wireless technology that uses radio waves to pair smart devices to be able to communicate or transfer information/files between devices (Blip Systems A/S, n.y.). It only takes a few seconds for a Bluetooth sensor to detect a signal, making it preferable in an environment of high speed (Gheorghiu et al., 2021). When a smart device is in discovery mode, and ready to pair with another device, it can be seen and registered by the sensors. The sensors register and restores the smart device identity number; the MAC (Media Access Control) address (Shoval & Ahas, 2016). Because of privacy concerns, the MAC addresses are scrambled. The data is collected without the knowledge and the consent of the individual (Versichele, Neutens, Delafontaine, et al., 2012). Therefore, it is a non-participatory research method with the advantage of not influencing people's travel behavior, but can also be considered as an ethical disadvantage as the one being recorded does not know about it (Hardy, 2020b, 2020c).

The Bluetooth technique has been used in the field of transportation for analysing the mobility of people and vehicles (Filgueiras et al., 2018) to get accurate information about a trip, e.g., travel time, speed, trajectories and origin-destination matrices (Michau et al., 2017). The implementation of Bluetooth sensors is low cost and easy but needs to be done with great care as there are many objects, such as printers and headsets, that use Bluetooth signals for pairing and can thus interfere with the aim of the research (Hardy, 2020c). This can create noise in the data and is common in urban environments. Other noise in the data that can interrupt the dataset and needs to be considered, both in urban and rural environments, are people outside of the research frame, e.g., people working in the area or inhabitants. Therefore, the data often needs a lot of processing and cleaning before being used as suitable research material (Bhaskar et al., 2015; Ellersiek et al., 2013).

3. 3. Materials and Methods

The Research Area

The research area is in southeast Iceland, around the glacial lagoon Jökulsárlón (Figure 2). There are no side roads to other parts of the country in this area, making it possible to use only two Bluetooth sensors to analyse the mobility patterns in the area. This area was therefore considered convenient to do this pilot study.

Jökulsárlón is one of the most visited nature-based destination in Iceland and was visited by more than 800,000 visitors in 2018 (Thórhallsdóttir, 2023). As it is located just beside the Ring Road it is easy to reach, but its distance from the main gateway, Keflavík International Airport, is around 380 km, approximately five hours' drive under good conditions and the nearest urban center is Höfn (Figure 1) in 80 km distance, east of Jökulsárlón.

There are three important attractions in the research area (Figure 2):

- The glacial lagoon Jökulsárlón.
- Ice caves west of Jökulsárlón, near Breiðá.
- Ice caves east of Jökulsárlón, in the Þröng area.

Jökulsárlón lies in front of the outlet glacier, Breiðamerkurjökull, part of Vatnajökull ice cap. It is a whole year nature-based destination (Árnason & Welling, 2019; Thórhallsdóttir et al., 2024). Breiðá and Þröng are mostly visited during the winter (Thórhallsdóttir, 2023), when the ice caves have formed and are deemed safe to enter. The ice caves are formed in the outlet glaciers of Vatnajökull by the flow of melt- and rainwater through the glacier. In 2018, 73,000 visitors came to Breiðá and almost 28,000 to Þröng.

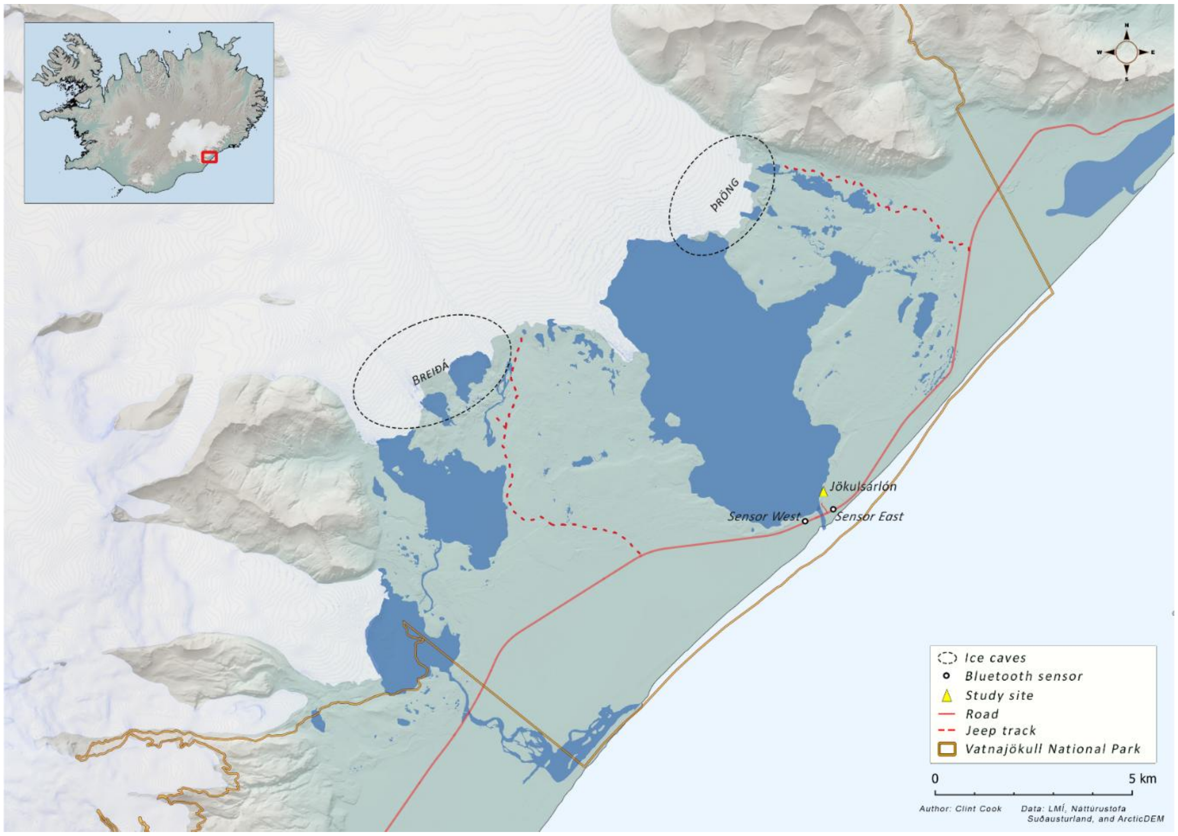

Figure 2. The research area.

The Study

This study spanned 1.5 years, from November 2017 to March 2019. In this paper, the year 2018 is analysed. It should be noted that all the traffic in the area is expected to be from travelers and no correction was made to exclude locals. Previous research by Guðmundsson (2020) found that around 78% of the traffic at the Ring Road by the mountain Lómagnúpur in the south was from tourists in rental cars. It is estimated that the other 22% are mostly locals or local service traveling between the capital area and their homes in the east.

Previous research indicated that most international visitors drove from the southwest area, along the South Coast, to Jökulsárlón and then turned back. The research also indicated that there was a seasonality in the travel direction, that could not be analysed with existing vehicle counters alone (Thórhallsdóttir et al., 2024).

To remedy this situation, two Bluetooth/Wi-Fi sensors were located beside the Ring Road, west and east of Jökulsárlón (Figure 2). It should be noted that even though the sensors can detect both Bluetooth and Wi-Fi signals, only Bluetooth signals were used. That is because it takes more time to detect a Wi-Fi signal, around one minute, than a Bluetooth signal, only a few seconds. The Wi-Fi signal is therefore more suitable for analysing the mobility of pedestrians (Hardy, 2020c) than people travelling in motorized vehicles. The sensors were set up on poles besides the highway, at 5 m height, as advised by the manufacturer.

The Danish manufacturer, Blip Systems, managed the sensors´ software and cleaned the data according to the researcher's instructions. All noise in the data was deleted by Blip Systems, that is all times that were less than 15 minutes in duration, which was considered the minimum travel time between sensors.

Except for the minimum detection time of 15 minutes that was set by Blip Systems, no attempt was made to exclude data from the analysis. The number of local staff in the Jökulsárlón area was expected to be less than 600, less than 1% of the total. This number was found by counting signals that came early in the morning from the east, before 10:00, and returned to the east, some were also seen at the western sensor. These recorded items had to stay more than six hours to be considered as local staff. The eastern sensor was used for this analysis as it is more likely that the staff live east of Jökulsárlón than west of it as the nearest town is Höfn (Figure 1).

The sensors detect signals from Bluetooth devices 24 hours a day. Because of privacy concerns, they cannot store the data from an individual device for more than 24 hours. There were six mobility options:

- A device coming from west of Jökulsárlón and seen at the western sensor and then heading back to the west again, not seen at the eastern sensor (WW). It was assumed that these travelers were coming from the capital area and returning.
- A device coming from west of Jökulsárlón, first seen at the western sensor, then seen at the eastern sensor but turns back and is seen again at the western sensor (WEW). Here it is also assumed that the travelers are coming from the capital area, they might stay for a night in the area east of Jökulsárlón and then return.
- A device coming from west of Jökulsárlón and seen at the western sensor and then again at the eastern sensor (WE). It is assumed that these travelers are driving the main road around Iceland. From the capital area they headed east and then north.
- A device coming from east of Jökulsárlón and seen at the eastern sensor and then heads back to the east again, not seen at the western sensor (EE). It is assumed that these people are mostly locals working in the Jökulsárlón area.
- A device coming from east of Jökulsárlón, first seen at the eastern sensor, then seen at the western sensor but turns back and is seen again at the eastern sensor (EWE). It is also assumed that these people are locals working in the area.
- A device coming from east of Jökulsárlón and seen at the eastern sensor and then again at the western sensor (EW). It is assumed that these visitors are driving the main road around Iceland. From the capital area they headed towards the north and then east.

The data from the sensors is sent via the telephone network to a server operated by Blip Systems which is accessible in real time on the internet. The historical data can also be downloaded from the database for further analysis (Ólafsson et al., 2017).

Additionally, to calculate the detection rate of the Blip Track sensors, two TRAFx magnetic vehicle counters were set up beside the sensors (Figure 2). The two vehicle counters were calibrated for errors. The calibration process of vehicle counters is explained in Thórhallsdóttir and Ólafsson (2017) and Thórhallsdóttir et al. (2021). In addition, data from vehicle counters previously set up at the access roads to Jökulsárlón, Breiðá and Þröng, all operated by Vatnajökull National Park were used (Thórhallsdóttir, 2023). Finally, data on overnight stays in the south and the east were used for the analysis. This data is collected by Statistics Iceland and is in open access on their website www.hagstofan.is. It needs to be noted that the overnight stay data register people while the data from Bluetooth sensors and the vehicle counters register vehicles.

The Detection Rate

During the research period, 2018, the sensors detected 59,193 items and the detection rate was in total 16%. It was 17% at the western sensor and 15% at the eastern sensor. The detection rate of the Bluetooth sensors was computed from the number of vehicles as counted by the vehicle counters as the sensors filter out the strongest signal at a time and excludes the other signals. Therefore, the sensors should only detect one signal at a time in one vehicle.

Table 1. Detected items from sensors and vehicles from vehicle counters.

	Total			**West**			**East**		
Month	**Counters**	**Sensors**	**Ratio**	**Counter**	**Sensor**	**Ratio**	**Counter**	**Sensor**	**Ratio**
Jan.	15,374	1,979	13%	9,041	1,326	15%	6,333	653	10%
Feb.	21,093	3,285	16%	12,094	2,037	17%	9,000	1,248	14%
Mar.	27,722	4,370	16%	15,623	2,679	17%	12,098	1,691	14%
Apr.	19,594	3,017	15%	10,848	1,748	16%	8,746	1,269	15%
May.	29,952	4,742	16%	15,293	2,434	16%	14,659	2,308	16%
Jun.	38,112	6,638	17%	19,558	3,406	17%	18,554	3,232	17%
Jul.	50,075	8,424	17%	25,604	4,334	17%	24,471	4,090	17%
Aug.	53,225	9,215	17%	27,618	4,869	18%	25,607	4,346	17%
Sep.	45,670	7,406	16%	23,713	4,045	17%	21,957	3,361	15%
Oct.	31,942	5,333	17%	17,354	3,062	18%	14,588	2,271	16%
Nov.	20,887	2,727	13%	11,665	2,003	17%	9,221	724	8%
Dec.	17,039	2,057	12%	9,622	1,441	15%	7,417	616	8%
SUM	370,684	59,193	16%	198,032	33,384	17%	172,652	25,809	15%

4. Results

The Mobility Patterns in the Research Area

Figure 3 explains the mobility patterns in the research area. Of the six mobility patterns, two of them were dominant. First, the so-called west to west (WW) travel option. Those are those travelers that came from the west and returned in the same direction. Secondly, the west to east (WE) mobility pattern, which is those that came from the west and continued to the east.

In January to March, the west-to-west pattern was dominant. In April, the west to west and west to east patterns were approximately equal. In May, the west to east mobility pattern took over as the most dominant one. This situation remained constant until October when the two patterns overlapped again. In November, the west-to-west pattern increased greatly whereas the west to east pattern decreased. In December, the west-to-west mobility pattern decreased and was like January, at the beginning of the year. The west to east pattern was the same in November and December (Figure 3).

The west to west (WW) and west to east (WE) mobility patterns were overall dominant, but there was also a medium pattern, east to west (EW), i.e., those that came from the east and continued towards the west, which increased during the summer, from May to October. The other three mobility patterns, east to east (EE), west to east to west (WEW) and east to west to east (EWE) were minor, and rather constant throughout the year (Figure 3).

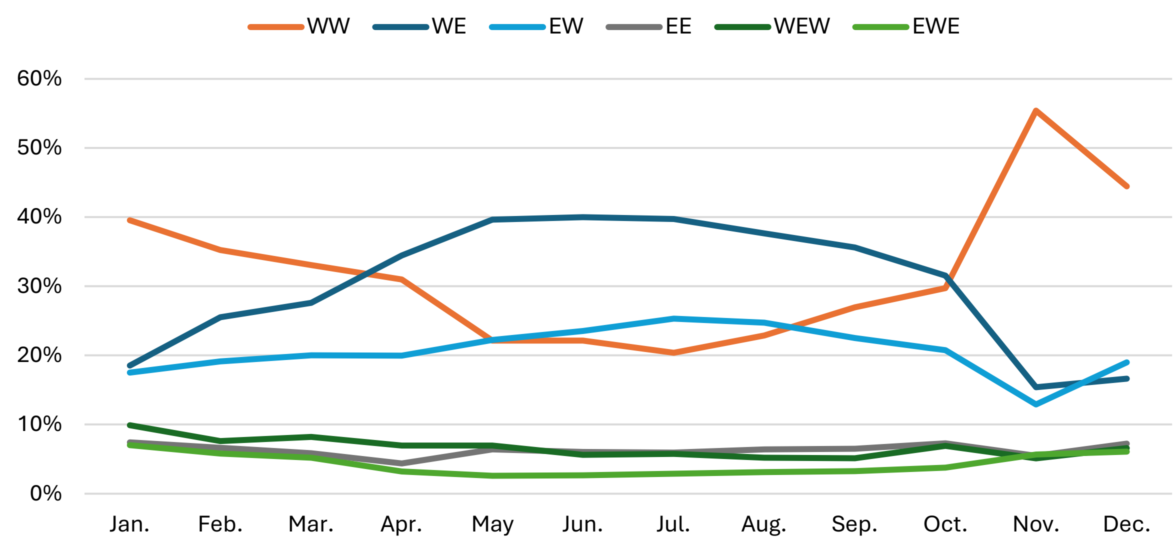

Figure 3. The mobility patterns in the Jökulsárlón area in 2018.

Dispersal in Space

Figure 4 shows the number of vehicles that arrived at the glacier lagoon Jökulsárlón and the nearby ice caves in the Breiðá and Þröng areas. The number of vehicles that went to the ice caves in the two areas, Breiðá and Þröng, are shown on the left axis and the number of vehicles that went to Jökulsárlón on the right axis. Because of malfunction in the device, there is unfortunately no data for January 2018 at Breiðá. Also, because of malfunction in the device at Jökulsárlón the numbers in January, September and October are estimates.

In 2018, the ice caves in the Breiðá area were visited much more often than those in the Þröng area. As seen on Figure 4, both destinations, Breiðá and Þröng, are winter destinations. Jökulsárlón, in contrast, is highly visited throughout the year, with a peak in August.

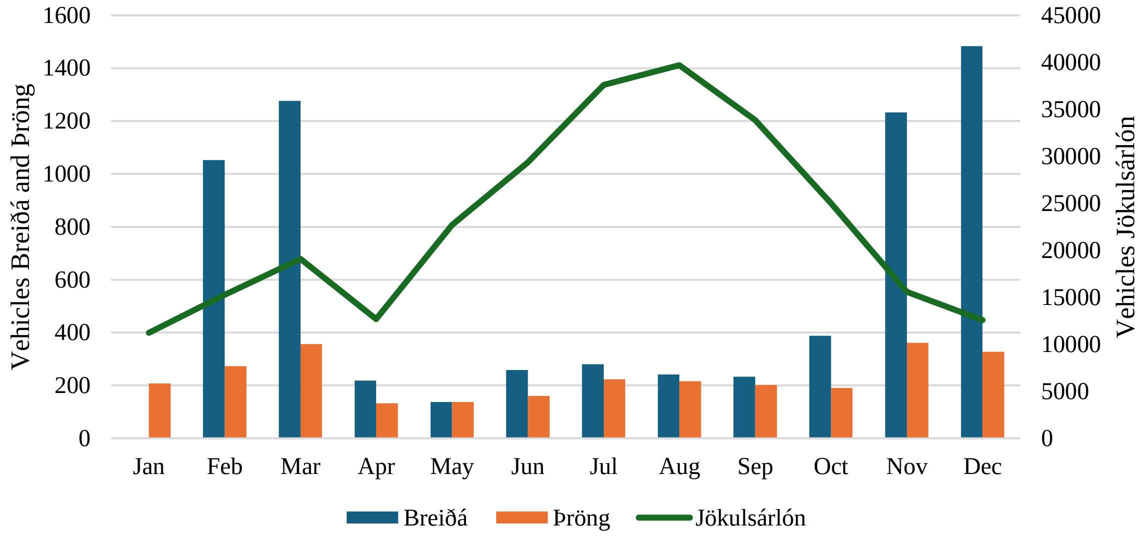

Figure 4. Number of vehicles.

Dispersal in Time

Figure 5 shows the average number of vehicles per hour between July, a typical summer month and December a typical winter month, computed from the vehicle counter to the glacier lagoon Jökulsárlón. The traffic at Jökulsárlón started early in the morning, at 8:00, independent of season. The traffic then increased from the morning until lunchtime, when there was a slight decrease. After lunch the traffic increased again and then dropped in the afternoon, depending on the season. The decrease in traffic occurred earlier during the winter than the summer (Figure 5), possibly due to limited daylight hours during the winter.

The same pattern was seen from the sensors in July and December (Figure 6). In July the peak was at 17:00, and 68% came between 11:00 and 18:00. In December the peak was at 12:00, and 90% came between 9:00 and 16:00. The traffic started earlier in the day in December than in July. That is probably due to the ice cave tours, starting early in the morning, at 9:00.

The average length of stay was longer during the winter months than during the summer. It was the longest in December (3.00 hours) and shortest in April (1.73 hours). This can both be seen in the average length of stay, the actual numbers, and the ratio. The ratio of those that stayed four hours or longer is higher during the winter months than the summer months and the shoulder seasons. Again, this is probably due to the ice cave tours, they last at a minimum of three to four hours. Those who came earlier stayed longer (Figure 6). Less than 1% stayed a full 24 hrs., that is they came and left the day after, and 76% of them were in June, July, and August. This may be explained by travelers travelling in campers and stay over a night at Jökulsárlón parking.

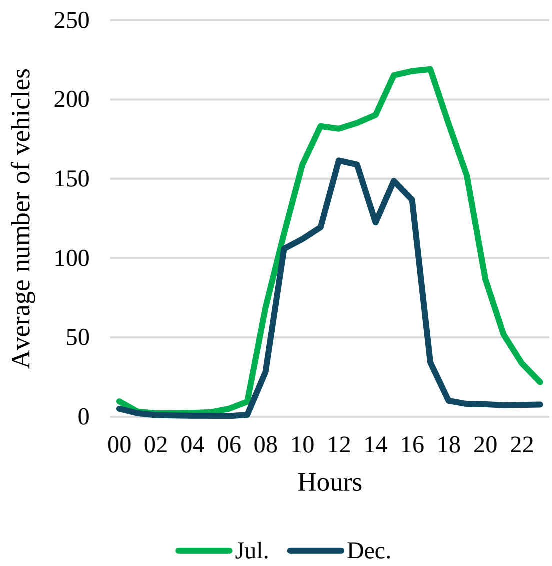

Figure 5. Hourly average number of vehicles at Jökulsárlón in July and December 2018.

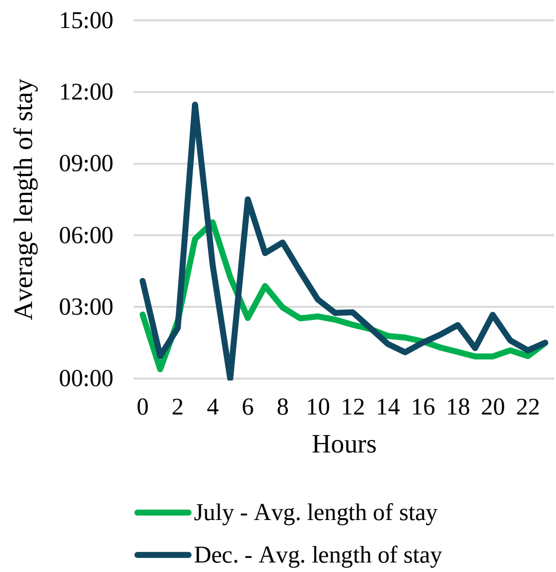

Figure 6. Average length of stay in July and December 2018.

Table 2. Length of stay.

	Less than 1 hour		**1 to 2 hrs.**		**2 - 4 hrs.**		**4 hrs. or more**		**Avg. length of stay**
	Number	**Ratio**	**Number**	**Ratio**	**Number**	**Ratio**	**Number**	**Ratio**	
Jan.	397	20%	573	29%	466	24%	543	27%	**2.87**
Feb.	758	23%	915	28%	770	23%	842	26%	**2.82**
Mar.	1,579	36%	1,286	29%	687	16%	820	19%	**2.27**
Apr.	1,048	35%	1,249	41%	477	16%	241	8%	**1.73**
May.	1,560	33%	1,741	37%	1,050	22%	391	8%	**1.84**
Jun.	1,990	30%	2,293	35%	1,714	26%	641	10%	**1.97**
Jul.	2,680	32%	2,759	33%	2,196	26%	787	9%	**1.94**
Aug.	2,696	29%	3,147	34%	2,467	27%	905	10%	**2.00**
Sep.	2,022	27%	2,604	35%	1,979	27%	801	11%	**2.08**
Oct.	1,528	29%	2,041	38%	1,161	22%	603	11%	**2.05**
Nov.	604	22%	816	30%	557	20%	749	27%	**2.85**
Dec.	426	21%	571	28%	435	21%	625	30%	**3.00**
Sum/Avg.	17,288	29%	19,995	34%	13,959	24%	7,948	13%	**2.15**

Overnight Stays

Figure 7 shows that visitors to Iceland mostly overnight in the capital area and in the south, independent of season. An analysis of the summer season shows the south overtakes the capital area for overnight stays. Most of the overnight stays are in downtown Reykjavík, on average 52% and in adjacent neighborhoods, 32%. Only 16% of tourists stay overnight elsewhere within the capital area. This is independent of season. In the south, the visitors overnight mostly in the mid-south, in the area close to Mýrdalsjökull (Figure 1), on average 30%, followed by the Hornafjörður area in the southeast, 25%. There are much fewer overnight stays in the east than in the capital area and the south, but those tourists that travel to the east overnight mostly in Múlaþing municipality region, on average 76%. That implies that the most visitors travel from the south and then head north and skip the Eastfjords in their travel. This mobility pattern is, however, only in evidence during the summer. During the winter hardly anyone overnights in the east. The data shows that during the winter season most visitors travel from the capital area and return (Figure 7).

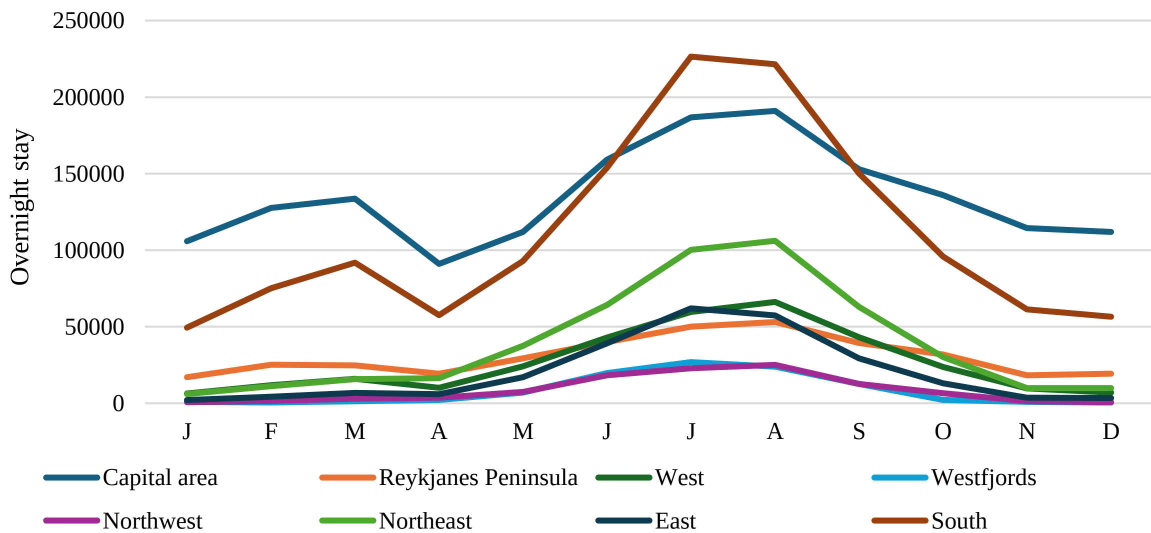

Figure 7. Overnight stay in Iceland in 2018.

5. 5. Discussion

This study explores the use of Bluetooth sensors as a tool to analyse tourism mobility patterns in a rural area, marking an innovative application of this technology in such a context. As a pilot study, the research highlights the economic advantages of Bluetooth sensors over traditional manual data collection methods, such as questionnaires and interviews. These traditional approaches are particularly challenging in rural areas due to limited staffing and the high costs associated with transportation and accommodation. In contrast, Bluetooth sensors offer a more efficient and reliable means of data collection, free from the recall biases that often affect self-reported data. However, it is important to acknowledge potential social biases inherent in this method, as it remains unclear whether specific social groups are more likely to use Bluetooth-enabled devices. Furthermore, while the sensors provide detailed data on movement patterns, they lack the capacity to capture the social and demographic dimensions that manual methods can offer.

Ethical considerations also merit discussion, particularly the concerns raised by Hardy (2020c) regarding the collection of data without individuals' knowledge or consent. While these concerns are valid, the risk of identifying individuals from the dataset is minimal. The data collected are anonymized, as MAC addresses are scrambled, and the dataset's large volume further reduces the likelihood of individual tracking. Nevertheless, privacy concerns should remain a key consideration in the application of this method.

Despite collecting 59,193 data points, the study achieved a detection rate of less than 20% of potential visitors, a limitation largely attributable to the fact that Bluetooth sensors only detect devices in pairing mode. This detection rate aligns with findings from previous research, which reported detection rates between 5% and 10% of traffic (Addinsight, 2017). However, as Bluetooth usage continues to increase globally, detection rates are expected to improve over time (Oosterlinck et al., 2017). Even for the disadvantages of the research method, its advantages make it an important addition to other methods to analyse tourism mobility patterns and the data is important for sustainable tourism planning and management. This research method is more economic than manual methods, as it can collect data continuously if wanted, and it is more reliable as it does not rely on one's memory.

The study utilized two sensors to analyse mobility patterns in the southeast, west, and east of Jökulsárlón. The findings provide valuable insights into temporal and spatial mobility patterns, though the nature of the method means that the dataset does not differentiate between international tourists, residents, or workers in the area. To address this limitation, assumptions about visitors' origins and behaviors were informed by previous research. For instance, Keflavík International Airport in the southwest is the primary entry point for most visitors to Iceland, leading to the assumption that travel typically begins in the southwest and progresses southward via rental cars (Thórhallsdóttir et al., 2024).

Seasonal variations in mobility patterns were evident. During winter, the west-to-west (WW) mobility pattern dominated, with visitors traveling from the capital area to Jökulsárlón and returning the same day. Visitors spent approximately one hour longer at sites in winter than in summer, a trend potentially explained by the nature of winter activities such as guided ice cave tours in the Breiðá and Þröng area, which require three to four hours to complete. Short winter holidays may compel visitors to prioritize specific, unique experiences, resulting in longer stays at individual sites. In contrast, summer travel was characterized by a west-to-east (WE) mobility pattern, with visitors spending less time at individual sites as they toured the entire island. Overnight stay data supported this pattern, with the south surpassing the capital area in overnight stays during summer months.

The inclusion of a third sensor, positioned further west, would have enhanced the ability to confirm traffic originating from the southwest. However, logistical and privacy constraints, including the 24-hour data storage limit imposed on the sensors, precluded broader sensor distribution. Nevertheless, the absence of alternative routes in the Jökulsárlón area suggests that the findings are indicative of more general mobility patterns in Iceland. These insights hold significant value for Icelandic tourism authorities in evaluating and refining sustainable tourism policies. Knowledge of mobility patterns of tourists at different scales is a crucial piece in all sustainability planning and management as it predicts for various infrastructure and services.

Therefore, Bluetooth sensors are a good addition to other methods to analyse tourism mobility patterns, especially in rural peripheral areas where the collection of data is time consuming and expensive but at the same time very important when planning for sustainable tourism. These methods have their limitations that need to be acknowledged and are not the ultimate solution to analyse tourism mobility patterns in rural peripheral areas.

6. 6. Conclusions

This study introduces and evaluates an innovative research method for analysing regional tourism mobility patterns (RQ1). Although the research was conducted in southeast Iceland, the methodology possesses broader applicability for mobility analysis in rural and peripheral regions. This approach is particularly valuable as it enables the efficient and cost-effective collection of extensive data on visitor movements, surpassing traditional methods such as surveys or interviews in terms of comprehensiveness and resource efficiency. Bluetooth technology serves as a useful complement to other mobility research methods, and the data derived from this method provides critical insights into visitor flow, volume, traffic density, crowding, and sequential movement. When combined with overnight stay data, these datasets collectively reveal where visitors spend the night and their movement patterns throughout the day. Consequently, this research furnishes essential baseline information on visitor mobility in both temporal and spatial dimensions, which is crucial for future studies as well as for sustainable tourism planning and management.

Bluetooth sensors represent an innovative research tool for mobility analysis in rural areas. The technological advancements of recent decades, particularly the proliferation of smart devices carried by individuals, have facilitated more economical and comprehensive analyses of tourism mobility patterns. However, these methods must be employed with caution due to privacy concerns. Therefore, while these new methods do not constitute a definitive solution for analysing tourism mobility patterns, they provide a valuable supplement to existing methodologies.

The findings of this study offer significant insights into the temporal and spatial mobility patterns within the research area (RQ2). Given the absence of side roads leading to other regions, individuals driving in the Jökulsárlón area originate either from the east or the south. As a result, the study’s findings provide valuable indications of broader mobility patterns in Iceland. These insights are particularly relevant for tourism authorities in assessing the effectiveness of current policies concerning sustainable tourism planning and management.

Understanding visitor mobility patterns across time and space is fundamental for sustainable tourism planning and management (Lew & McKercher, 2006), as it directly influences infrastructure and service planning at both regional and national levels. The research method presented in this study is particularly beneficial for policymakers and destination managers in regions where tourism is characterized by a dominant core that influences mobility patterns extending into peripheral rural areas and nature-based destinations, which are often dispersed across large geographic areas, such as in Arctic regions. Advances in transportation have reduced the constraints posed by distance from central hubs, enabling visitors to travel long distances between sites within a single day before returning to central hubs for overnight stays. This mobility pattern raises sustainability concerns, particularly in the context of climate change, as tourists predominantly rely on rental vehicles for brief site visits. For instance, in Jökulsárlón during the winter season, visitors frequently travel from the southwest, spend approximately two to three hours at the site, and subsequently return to the capital region for overnight accommodation. Despite the relatively efficient transportation infrastructure and the availability of numerous accommodation options along the route, this mobility pattern is unsustainable for local communities. The transient nature of visitor behavior minimizes economic contributions to the region while simultaneously exacerbating pressure on local infrastructure and natural environments, potentially leading to tensions among residents.

7. 7. References

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